UNIVERSITY OF ALBERTA

# Ichnology, Sedimentology, and Stratigraphic Architecture of the Notikewin Member of the Spirit River Formation in the Wapiti Area of Alberta

by

**Glenn Anton Schmidt**

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science.

Department of Earth and Atmospheric Sciences

Edmonton, Alberta

Spring 2002

National Library of Canada
Acquisitions and Bibliographic Services
395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque nationale du Canada
Acquisitions et services bibliographiques
395, rue Wellington
Ottawa ON K1A 0N4
Canada

*Your file Votre référence*

*Our file Notre référence*

The author has granted a non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of this thesis in microform, paper or electronic formats.

L'auteur a accordé une licence non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de cette thèse sous la forme de microfiche/film, de reproduction sur papier ou sur format électronique.

The author retains ownership of the copyright in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

L'auteur conserve la propriété du droit d'auteur qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

0-612-69757-6

Canada

**University of Alberta**

**Library Release Form**

**Name of Author:** Glenn Anton Schmidt

**Title of Thesis:** Ichnology, Sedimentology, and Stratigraphic Architecture of the Notikewin Member of the Spirit River Formation in the Wapiti area of Alberta

**Degree:** Master of Science

**Year this Degree Granted:** Spring, 2002

Permission is hereby granted to the University of Alberta Library to reproduce single copies of this thesis and to lend or sell such copies for private, scholarly or scientific research purposes only.

The author reserves all other publication and other rights in association with the copyright in the thesis, and except as herein before provided, neither the thesis nor any substantial portion thereof may be printed or otherwise reproduced in any material form whatever without the author's prior written permission.

(Permanent Address)

Box 17 Site 14 RR4
Edmonton AB T5E 5S7

Date: April 16, 2002

*"It would be possible to describe everything scientifically, but it would make no sense; it would be without meaning, as if you described a Beethoven symphony as a variation of wave pressure."*

*Albert Einstein*

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate studies and Research for acceptance, a thesis entitled **Ichnology, Sedimentology, and Stratigraphic Architecture of the Notikewin Member of the Spirit River Formation in the Wapiti Area of Alberta** submitted by **Glenn Anton Schmidt** in partial fulfillment of the requirements for the degree of **Master of Science.**

.....

Dr. S.G. Pemberton (Supervisor)

.....

Dr. C.R. Stelck (Committee Member)

.....

Dr. D.A. Craig (Committee Member)

Glenn Schmidt April 16, 2002.

## DEDICATION

*For Mom and Dad*

## ABSTRACT

In the subsurface of the Wapiti area in West Central Alberta, the Notikewin Member represents a variety of marginal marine siliciclastic depositional environments. In this thesis, the Notikewin is studied between townships 65 to 68 and ranges 7 to 13 west of the Sixth Meridian. Fifty one cores were compared with 360 well logs within this area.

By interpreting sedimentologic and ichnologic aspects and applying stratigraphic principles based on bounding discontinuities, the Notikewin Member can be divided into four units (T1, R1, R2 and R3). T1 is the lowermost unit and represents deposition in a transgressive, wave-dominated estuary. R1 records the development of a regressive strandplain. During deposition of R2, a barrier spit was formed that prograded for a short distance. R3 represents a basinward shift of the shoreline resulting in the accumulation of continental deposits within the study area.

This study reveals that contrary to previous interpretations, the Notikewin did not prograde a great distance as a barrier island/lagoon complex. In addition, observations regarding the nature of contacts in the Notikewin have implications pertaining to the validity of applications of the "forced regressive" shoreline model.

## ACKNOWLEDGEMENTS

There are few times in a person's life that one has the opportunity to reflect on where they have come to in life, and how they embarked on the paths that led them there. For me it is a great signpost in my journey and I am grateful for the chance to put to paper the heartfelt thanks I feel for those who traveled with me or helped me along. I must first thank the three people who first inspired me to study and enjoy geology: George, Murray and Tom.

Of all the people I know, I cannot think of anyone that I would rather have for a supervisor than Dr. George Pemberton. He provides both the inspiration and freedom to think. These I feel are the most important aspects of any graduate study. One day in my undergraduate fourth year Murray Gingras walked up to me and said "Hey Glenn, you should think about doing a thesis with George". This perhaps chance comment from Murray put a light in my mind, and later that same day I had filled out the application form for grad studies. Murray's contributions weren't limited to that day; he was always there throughout my studies to provide much needed criticism and practical advice. Tom Saunders had a great ability to paint a clear picture with words of many a geological concept. He took ideas beyond their mundane appearance on paper and put them out someplace where they were more fun to dream and imagine about.

I would like to thank my Committee; George, Dr. Stelck and Dr. Craig. The anxiety I had before my defense was soon forgotten as I greatly enjoyed and was inspired by your questions and comments.

I made some great friends and companions while here at the U of A. The greatest and truest of those is Kimberly Earle, who is more than my best friend. Thanks for everything.

The rest of the gang of boozehounds and miscreants really made my stay here memorable. I can look back with pride and one-up anyone who tells a tale of the crazy antics of their friends. Jason Lavigne, Eric Hanson, Jason Frank, Steve Hubbard, Jeff Reinprecht and Ian Armitage and others in the IRG. When you guys weren't kicking down my door, or launching flares through my window, you were helping me learn about life, guitars, geology, music, philosophy and a bunch of other miscellaneous topics that have become some of the most important things to me.

While I was struggling with the inadequacies of my own writing, several people helped my providing critical review of various parts of my thesis. Thanks to Steve, Eric, Jay, Marianne, Clark, Andre, and Kimberly.

Lastly, I would like to thank my parents to whom this thesis is dedicated. Thank-you for your patience and help throughout the years.

## TABLE OF CONTENTS


**Chapter 1 Introduction** 1

Research rationale 1

Study area 2

Past workers 3

Age and biostratigraphy 5

Tectonic Elements 7

Stratigraphic relations 10

Palaeogeography 14

Reservoir characteristics 17

**Chapter 2 Facies Descriptions and Interpretations** 19

Facies association 1 Prodelta/offshore transition 19

Facies 1a Irregularly interbedded sandstone and shale 19

Facies 1b Rhythmically laminated fine-grained sandstone and shale 25

Facies 1c Intensely bioturbated silty shale 31

Facies association 2 Lower shoreface deposits 32

Facies 2a Hummocky to swaley cross laminated sandstone 33

Facies 2b Intensely bioturbated fine sandstone and shale 40

Facies association 3 Upper-shoreface to Foreshore 44

Facies 3a Inter-bedded sandstone and polymodal conglomerate 47

Facies 3b Bimodal to unimodal conglomerate and coarse sand 55

Facies association 4 Marginal marine restricted deposits 64

Facies 4a Bioturbated shale with fine sandstone 64

Facies 4b Ripple laminated to parallel laminated bioturbated sandstone 69

Facies association 5 Continental to fluvial deltaic 75

Facies 5a Sparsely to non-bioturbated silt, shale and coal 75

Facies 5b Planar laminated to massive sandstone 78

Facies 5c Polymodal angular conglomerate 81

Facies 5d Coal 81

**Chapter 3 Environments of Deposition and Stratigraphy** 83

Barrier Formation 83

Stratigraphic surfaces 86

Notikewin depositional sequences 88

**Chapter 4 Conclusions** 100

**References** 102

**Appendix I** 113

**Appendix II** 150

## LIST OF FIGURES


| Figure | | Page |
|---|---|---|
| Figure 1.1 | Location map of the study area. | 3 |
| Figure 1.2 | Biostratigraphic nomenclature for the Albian of NW Alberta | 7 |
| Figure 1.3 | Structural elevation of the top of the Notikewin. | 9 |
| Figure 1.4 | Stratigraphy of the Notikewin and equivalents. | 10 |
| Figure 1.5 | Sequence stratigraphy of the Spirit River Formation | 12 |
| Figure 1.6 | Representative well log signature for the Notikewin | 13 |
| Figure 1.7 | Palaeoseaway during the Late Early Albian | 15 |
| Figure 1.8 | General palaeogeography | 16 |
| Figure 1.9 | Estimated gas reserves for the Notikewin in Alberta | 18 |
| Figure 2.1 | Facies table part 1 | 20 |
| Figure 2.1 | Facies table part 2 | 21 |
| Figure 2.2 | Facies 1a,c | 23 |
| Figure 2.3 | Facies 1b | 26 |
| Figure 2.4 | Facies 1b | 29 |
| Figure 2.5 | Lower shoreface deposits | 34 |
| Figure 2.6 | Moderately bioturbated lower shoreface deposits | 38 |
| Figure 2.7 | Facies 2b | 41 |
| Figure 2.8 | Upper shoreface deposits | 45 |
| Figure 2.9 | Upper shoreface trace fossils | 48 |
| Figure 2.10 | Beach deposits | 57 |
| Figure 2.11 | Isopach of the beach conglomerate | 60 |
| Figure 2.12 | Gross sand and conglomerate of the lower Notikewin member | 62 |
| Figure 2.13 | Lagoon/bay deposits | 65 |
| Figure 2.14 | Tidal channel deposits | 70 |
| Figure 2.15 | Tidal channel surfaces | 72 |

| | | |
|---|---|---|
| Figure 2.16 | Channel deposits | 76 |
| Figure 2.17 | Gross channel sand ispoach | 80 |
| Figure 3.1 | Stratigraphic cross-section B to B' | 89 |
| Figure 3.2 | Palaeogeography during the depostion ot T1 | 91 |
| Figure 3.3 | Palaeogeography during the depostion ot R1 | 92 |
| Figure 3.4 | Palaeogeography during the depostion ot R2 | 94 |
| Figure 3.5 | Stratigraphic cross-section A to A' | 95 |
| Figure 3.6 | Succession of facies through the Notikewin R2 | 96 |
| Figure 3.7 | Palaeogeography during the depostion ot R3 | 98 |
| Figure 3.8 | Interpreted palaeogeography for the Notikewin Member | 99 |

# CHAPTER 1

## INTRODUCTION

**Research rationale:**

The purpose of this study is to achieve a better understanding of the internal stratigraphic relations of the Notikewin Member. Although similar deposits of the Falher Members have been extensively studied (Cant, 1995; Rouble and Walker, 1994, 1997; Arnott, 1993; Caddel, 1999), the Notikewin has received relatively little attention. Except for outcrop studies of the age equivalent Gates Formation in British Columbia (Carmichael, 1981, 1983, 1988), only the external stratigraphy of the Notikewin has been described in past works (Cant 1984, 1995, 1996). Despite similarities with the Falher cycles, the Notikewin was noted to be profoundly different; both in the distance that it prograded (Smith, 1984; Leckie, 1985), and in the maintenance of a barred shoreline configuration (Leckie, 1985). With the increased studies of the Galveston Island Barrier in Texas during the early 1980's, workers attempted to apply these studies to ancient deposits. As a result, many ancient deposits were interpreted as progradational barrier islands. At the time, it was not realized that the barrier island nearshore configuration represents a time of instability of the shoreline, and that temporally significant progradation, while maintaining a barred configuration, is unlikely (Roy *et al.*, 1994).

Other sequence stratigraphic advances have been made over the last two decades. The recognition of the utility of depositional hiatuses in stratigraphic interpretation has allowed the reinterpretation of many formations. Of particular interest to studies in the Spirit River Formation is the forced regression shoreline model (Posamentier *et al.*, 1988) which has been proposed as an alternative to offshore bars forming in place. This new model has been cited as a possible mechanism for some of the sharp-based sequences in the Spirit River Formation (Cant, 1995; Caddel, 1999; Armitage, 2002), and as a possible mechanism by which barriers may prograde (Roy *et al.*, 1994). The emphasis

on sequence stratigraphy and the role of relative sea level has sometimes resulted in an over-complication of stratigraphic interpretation. Walther's law is frequently ignored, and surfaces which could easily represent something as simple as delta lobe switching are often attributed to sea-level change (eg. Ainsworth, 1992; Plint, 1996).

Bearing this in mind, it was decided that the stratigraphic and depositional aspects of the Notikewin Member required revision and reinterpretation. With the ever increasing data-base available in the form of core cut from wells drilled by petroleum companies, it is now possible to study the Notikewin in greater detail than hitherto possible. Combination of the concepts of sedimentology and ichnology will provide new insight into the nature of the Notikewin member. This study will address the questions of why the Notikewin Member developed a barred configuration, why it prograded so far into the basin, and how gravel sized particles were transported to and along the shoreface.

**Study area:**

Consideration for the location of the study area took into account two basic requirements. The first is that it must have adequate core and well control for the generation of a sufficient database. The second criteria is that the study must be located in an area that will provide advantageous information for petroleum exploration. For this reason, the study area centers around the Wapiti gas field in the west central portion of Alberta (Figure 1.1). It extends from townships 65 to 68 and ranges 7 to 13 west of the 6th meridian. In this area, extensive exploration for gas contained within the Notikewin Member has resulted in the generation of numerous geophysical well logs and a large number of cores. Initial examination of the study area demonstrated that there was good core control over the entire extent of the area. Subsequent analysis has shown that most of the cores are oriented along depositional strike of the main reservoir unit, with outlying core typically only representing the basal few meters of the Notikewin. In this study, 51

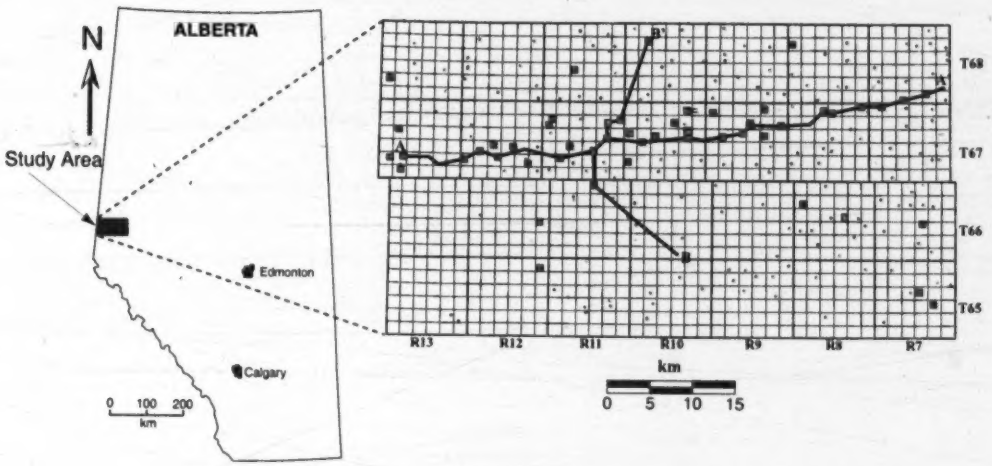



**Figure 1.1. Location map of the study area. Locations with logged core are marked with green squares. The locations of cross sections A-A' and B-B' are also indicated.**

cores were examined and compared with 360 geophysical well logs. These were used to construct maps and cross-sections over the study area and develop a stratigraphic and paleogeographic interpretation of Notikewin sediments.

**Past workers:**

Before the development of subsurface petrophysical and core databases, study of the Lower Cretaceous in North Western Alberta depended upon the examination of extensive outcrops created by the down-cutting of modern river systems. Prior to the construction of roads and railways into Alberta's north in the 20th century, major transportation was focused along main waterways, principally the Peace and Athabasca Rivers. It was along these rivers and their tributaries that most of the early geological investigations were performed.

Early workers of the Lower Cretaceous include Sir Alexander Mackenzie in 1792

(quoted in McConnell 1893), Alfred R.C. Selwyn (1878), G.M. Dawson (1881) and R. Bell (1885). It was not until investigations by R.G. McConnell (1893) were undertaken that nomenclature for the strata along the Peace River began to be developed. Sediments of the Lower Cretaceous were seen to crop out east of Vermilion Chutes along the Peace River where they rested unconformably on the underlying Devonian Limestone. McConnell (1893) described these strata as the Loon River Shale. These sediments continue to crop out upriver, until near the mouth of the Notikewin River (named Battle River in McConnell's 1893 report), where they are divided by a sandstone unit, which was named the Peace River Sandstone. This sandstone layer continuously outcrops along the mouth of the Peace River until it gradually dips beneath the level of the river near the Smoky River Forks. Further studies of outcrops of the Peace River sandstone were undertaken by McLearn (1918), who briefly described the Peace River Formation. In 1949 Wickenden (1951) returned to Peace River and performed more detailed work dividing the Peace River Formation into four members. These were named from oldest to youngest: the Basal Member, Middle Shale Member, Cadotte Member and Continental Member.

In order to develop a consistent nomenclature, Workman (1954) renamed sediments of the Lower Cretaceous. The Continental Member became the Paddy Member, and the Middle Shale Member became the Harmon Member. Together with the Cadotte, these three members were then grouped together and termed the Peace River Formation. Wickenden's (1951) Basal Member was removed from the Peace River Formation and divided into the underlying Falher Member and the overlying Notikewin Member. These two members were grouped together with the underlying Wilrich Member and were collectively termed the Spirit River Formation.

Following investigations by these early workers, the members of the Spirit River Formation have received more individual attention (Leckie and Walker, 1982; Carmichael 1983,1988; Cant, 1984, 1994; Leckie 1985, 1986, 1989; Arnott, 1994; Rouble and Walker

1994, 1997; Caddel, 1999). The increased degree to which the Notikewin Member was being studied was likely due to both the development of a clear nomenclature, and the discovery of producible gas reserves within the member in the Belloy, Gordondale, and Heart River fields in 1951 and 1952. Continued discovery of hydrocarbons within the Notikewin through to the present and the ever increasing supply of subsurface data which becomes available, have allowed the member to be studied to an increasing level of detail. May (1967) began more detailed sedimentological work on the Spirit River Group in general.

The Notikewin has been the most extensively studied since the discovery of the Elmworth field deep basin gas reserves. Within the study area, the Notikewin has been briefly described (Smith *et al.*, 1984; Jackson, 1984). These studies were primarily based on interpretations of well logs, as little core was available at the time. In the Kaybob field area, Gardiner (1982) has studied nearshore sediments of the Notikewin. Extensive outcrop studies have been undertaken to the west at Falls Mountain, Bullmoose Mountain, Mt. Spieker, and Mt. Frame , where the Notikewin equivalent Gates Formation has been thrust to the surface (Stott, 1968, 1982; Carmichael, 1981, 1983,1988; Leckie and Walker, 1982; Leckie, 1985, 1986, 1989). General stratigraphic relations have been described by Cant (1985, 1995).

**Age and biostratigraphy:**

Due to the modern prevalence of isotopic age dating, and the difficulty of detailed paleontological work, biostratigraphic methods presently receive very little attention. The values of paleontological studies are not limited to age determination, and should not be underestimated. Paleogeographic reconstructions of the Cretaceous are enhanced by the examination of ammonite and foraminiferal faunas (eg. Williams and Stelck, 1975; Jeletzky, 1971; and Kauffman, 1984). The construction and correlation of fossil zones

are imperative to the understanding of the geographic configuration, salinity, and depth of the interior seaway, and as such it is appropriate to discuss the fossil zonation that has previously been applied to the Spirit River Formation.

Paleontological work on Spirit River equivalent strata has been outlined by Nauss (1947), Wickenden (1951), Mellon and Wall (1956), Stelck *et al.* (1956), Singh (1971), North and Caldwell (1975), and Stelck and Kramers (1980). However little work has been performed specifically developing the biostratigraphy of the Spirit River Formation. The Spirit River Formation carries a diverse selection of foraminifera and flora as well as ammonites of *Freboldiceras*, *Beudanticeras* and *Arcthoplites* genera.

Foraminiferal biozonation of the Cretaceous has been outlined by Caldwell *et al.* (1978) and Caldwell *et al.* (1993). Deposition of the Spirit River Formation is shown to be contained within the *Gaudryina nanushukensis* foraminiferal zone, which is divided into 6 subzones (Figure 1.2). The lower 3 represent the Lower Albian, and the upper 3 represent the Middle Albian. The lowermost two subzones, the *Rectobolivia* sp, and *Trochammina mcmurrayensis* represent the deposition of the Gething and Bluesky Formations. The overlying Spirit River Formation is represented by the *Verneuilinoides cummingensis-Marginulinopsis collinsi* subzone. This zone has been divided into two biozones; the *M. collinsi*, which contains predominantly calcareous foraminifera, and the *V. cummingensis* where agglutinated foraminifera dominate. The *M. collnsi* biozone is thought to represent a transgressive, offshore sequence with generally normal salinity (Caldwell *et al.*, 1993). Conditions such as these would generally be found during deposition of the Wilrich member. The *V. cummingensis* biozone has been described as representing a regressive, marginal marine environment, which may be somewhat brack-

| Formations | | Molluscan Zones | Foraminiferal subzones | Foraminiferal zones | Substage |
|---|---|---|---|---|---|
| PEACE RIVER FORMATION | | *Stelckiceras liardense* | *Ammobaculites wenonahae* | *GAUDRYINA NANUSHUKENSIS* | MIDDLE ALBIAN |
| | CADOTTE MEMBER | *Gastroplites allani* | *Ammobaculites* sp. | | |
| | HARMON MEMBER | *Gastroplites kingi* | *Haplophragmoides multiplum* | | |
| | | *Pseudopuchellia pattoni* | | | |
| SPIRIT RIVER FORMATION | NOTIKEWIN MEMBER | *Freboldiceras remotum* | *Verneuilinoides cummingensis - Marginulinopsis collinsi* | | LOWER ALBIAN |
| | FAHLER MEMBER | | | | |
| | WILRICH MEMBER | *Subarcthoplites mcconnelli* | | | |
| BLUESKY FM. | | | *Trochammina mcmurrayensis* | | |
| GETHING FM. | | *Pachygrycia canadensis* | *Rectobolivina* sp. | | |

**Figure 1.2. Biostratigraphic nomenclature for the Lower and Middle Albian of Northwestern Alberta (Caldwell et al., 1993).**

ish (Caldwell *et al.*, 1993). Conditions such as these predominate during the deposition of the Falher and Notikewin members. The middle Albian in the Peace River Plains area is represented by the *Haplophragmoides multiplum* and *Ammobaculites* sp. subzones which comprise the Harmon and Cadotte members of the Peace River Formation.

Due to erosion during the late Albian, the final foraminiferal subzone of the Middle Albian, (*Ammobaculites wenonahae* ) and the next 6 foraminiferal subzones of the upper Albian are not represented in the sedimentary record of the Peace River Plains. The next subzone represented in this region is the *Reophax troyeri* subzone of the late Late Albian (Stelck and Leckie, 1990).

**Tectonic Elements**:

During the Albian, Haq *et al.* (1987) showed that there was a global second order sea level rise. In the Western Canada Sedimentary Basin, complicating factors of

variable sediment supply and subsidence obscure this rise in sea level. Sedimentation within the Basin has been shown to be a result of either third order tectonic or eustatic events by several previous workers (e.g. Jeletzky, 1978; Monger and Price, 1979; Cant and Stockmal, 1989). Given the tectonically dynamic setting during the Albian, tectonic events seem to be the dominant cause. However tectonic events are more difficult to correlate then eustatic changes, and as such, they are often dismissed rather than studied (eg. Hancock, 1975). Undershultz (1991) demonstrated that eustasy had little effect on the rate of sediment influx, and noted that the upper Spirit River Formation had one of the highest sedimentation rates when compared to other formations from the mid-Jurassic to end-Cretaceous. This implies that tectonic events, which caused either a greater amount of sediment influx or a greater amount of basinal subsidence, are the primary cause for deposition and preservation of the Notikewin Member.

Accommodation for deposition of Mannville era sediments was highest in the Liard Basin, Alberta Foredeep, and Peace River Arch area (Hayes *et al.*, 1994). The Liard Basin has only received minimal study, as it is still predominantly a frontier basin with few well penetrations. However, it has been noted by Leckie *et al.* (1991) to contain a thick Mannville-era succession. The region over the Peace River Arch (embayment) has been noted to be subsiding during the Mesozoic, which has allowed for an increased amount of accommodation space in the Peace River area (Cant, 1988). Increased accommodation space in the foredeep during the Albian resulted from downwarping of the crust during tectonic loading.

Mineralogical studies of the Notikewin demonstrate that provenance is from the Cordillera (Gardiner, 1982). Leckie (1985) cited Monger and Price (1979) and Porter *et al.* (1982) as describing the deposition of the Notikewin to be a result of collision of the Stikinia composite terrane.

Subsequent deformation of the Notikewin occurred as a result of continual

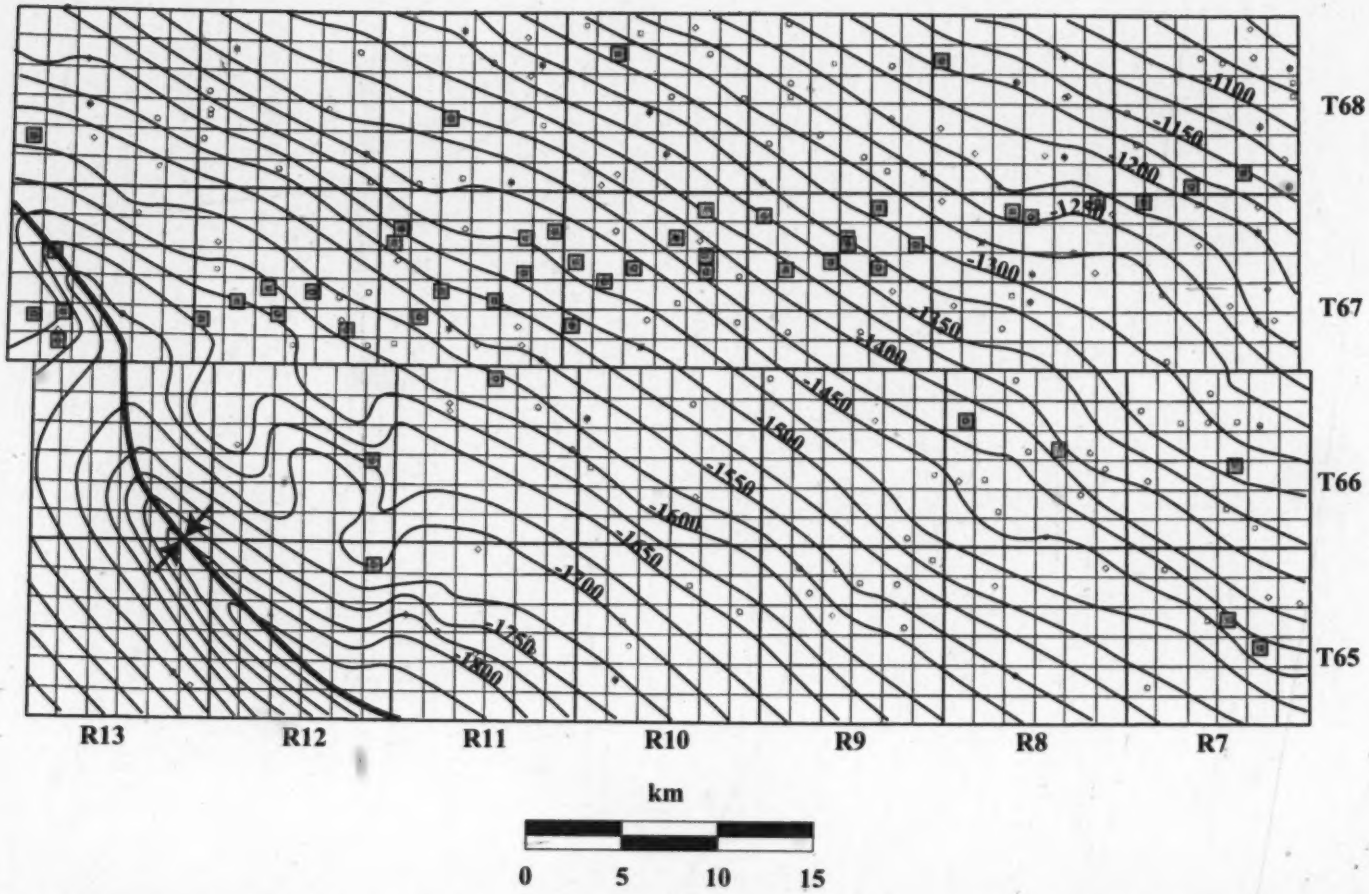



**Figure 1.3. Structural elevation (25 meter intervals, meters below sea level) of the top of the Notikewin Member within the study area. Approximate location of syncline is als shorwn (south west portion of study area).**

mountain building during the Laramide Orogeny from the middle Cretaceous to the Eocene. Recent erosion of the Notikewin Member is a result of down-cutting of modern river systems, namely the Peace River and its tributaries.

Within the study area, the general structural trend of the Notikewin is dipping towards the south west (Figure 1.3). In the southwest portion of the study area, a syncline disrupts this regional trend. No other major structural features were noted in this study.

**Stratigraphic relations:**

The Notikewin Member is defined by various fossil zones discussed previously which gives it an age of late Early Albian (Caldwell *et al.*, 1993; Jeletzky, 1971; Stelck and Kramers, 1980). It is therefore equivalent with the Upper Mannville, Grand Rapids A Member, Upper Gates Mountain Park Member, and middle Scatter Formation (Figure 1.4).

The Notikewin is overlain conformably by the Harmon Member of the Peace River Formation. The upper boundary is placed at the first main sandstone below the

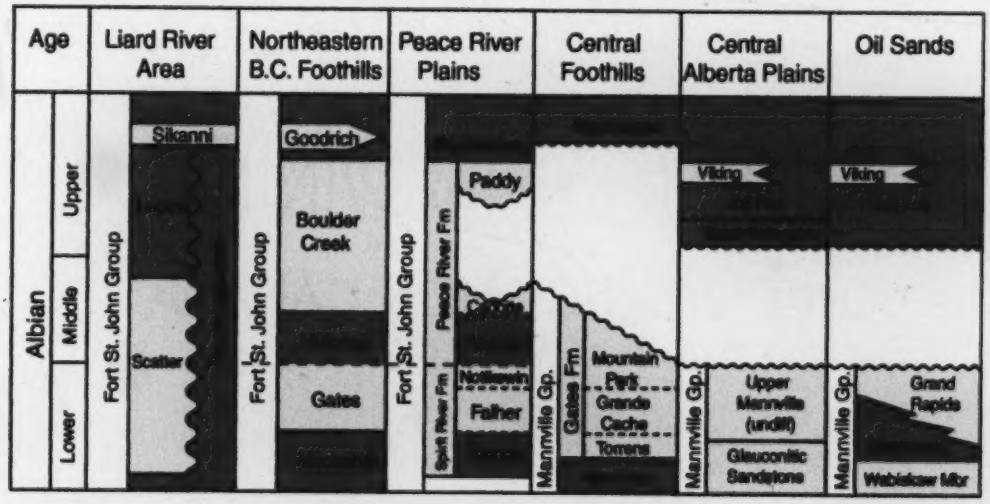



**Figure 1.4. Stratigraphic table of Notikewin Member and equivalents modified from Smith (1994).**

shale beds of the Harmon. The lower boundary is transitional with the Falher "A" Member, and is picked where the Notikewin Member is not predominantly sandstone (Badgley, 1952). In the type location, the Notikewin and the underlying Falher are differentiated based primarily on the marine nature of the Notikewin as compared to the predominately non-marine deposits of the Falher. On this basis, Leckie (1985) picked the base of the Notikewin at the top of the highest Falher coal, carbonaceous shale or coarse-grained sandstone to conglomerate.

Notikewin sediments in the Wapiti area somewhat loosely fit these parameters. Complicating factors include coal beds in the upper portions of the Notikewin and an unconformable contact with the underlying Falher Member. As the Notikewin Member generally contains sand or conglomerate at its base, it is occasionally difficult to differentiate from the Falher based on the criteria of Leckie (1985). In addition the sediments of the upper Falher may be deposited in a marine to marginal marine environment, which may be difficult to separate from the Notikewin marine deposits.

The Notikewin is present in the subsurface in the Peace River Plains region of Alberta and British Columbia. Outcrops of the Notikewin in Alberta are present along the Peace River between the mouth of the Notikewin River and just north of the town of Peace River. Age equivalent outcrops of the member are found along the Rocky Mountain Thrust Belt, where it has been thrusted to the surface west of the Gwillim fault (Leckie, 1985).

The type section of the Notikewin occurs near the mouth of the Notikewin River, where it was studied by Wickenden (1951). The type section for the subsurface is between 2678 to 2770 feet of depth in the Imperial Spirit River No. 1 well (00/12-20-78-06w6-00).

The Notikewin consists of fine to medium grained sandstone and conglomerate interbedded with shale. Ironstone concretions and glauconite occur locally (Badgley, 1952). The Notikewin is dominantly marine, although some minor non-marine layers

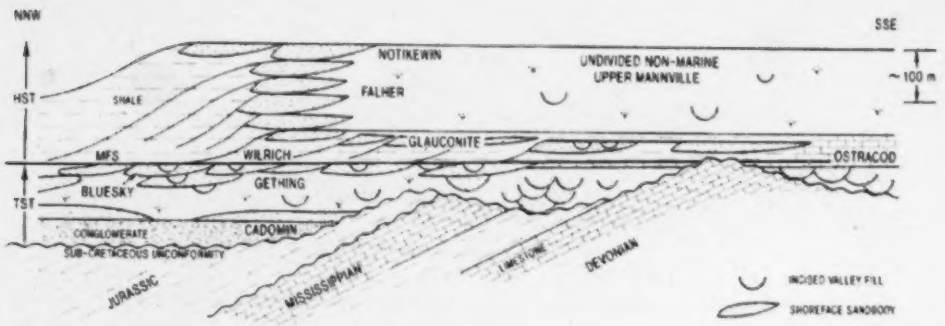



**Figure 1.5. General sequence stratigraphy of the Spirit River Formation (upper Mannville equivalent). (Cant, 1996 figure 3)**

occur in the southern area of the Peace River region (Leckie, 1985).

Cant (1984) described 8 transgressive-regressive sequences in the Spirit River Formation. He showed the Spirit River Formation to be representative of a third order sequence, with each of the 8 cycles representing fourth order cycles. Of these fourth order cycles, the Notikewin was shown to represent the last transgressive-regressive cycle, which was recognized as a single coarsening upwards sequence. The Notikewin has been described as separating seaward in the basin into two coarsening upward cycles due to a minor transgression (Cant, 1984). Overall the Notikewin member has been described as the upper member of a highstand systems tract that encompasses the Spirit River Formation. This relationship has been described by Cant (1996), and is depicted in Figure 1.5.

The well log depicted in Figure 1.6 is representative of the general character of the Notikewin Member in the Wapiti area. Initial interpretations of the well log signatures for purposes of general correlation were based on models developed by Smith *et al.* (1984). In general this correlation consists of a coarsening or cleaning upwards signature on the gamma ray log, in the past interpreted as a single regressive shoreline sequence (Cant, 1984). Overlying deposits of the upper Notikewin represent an increase

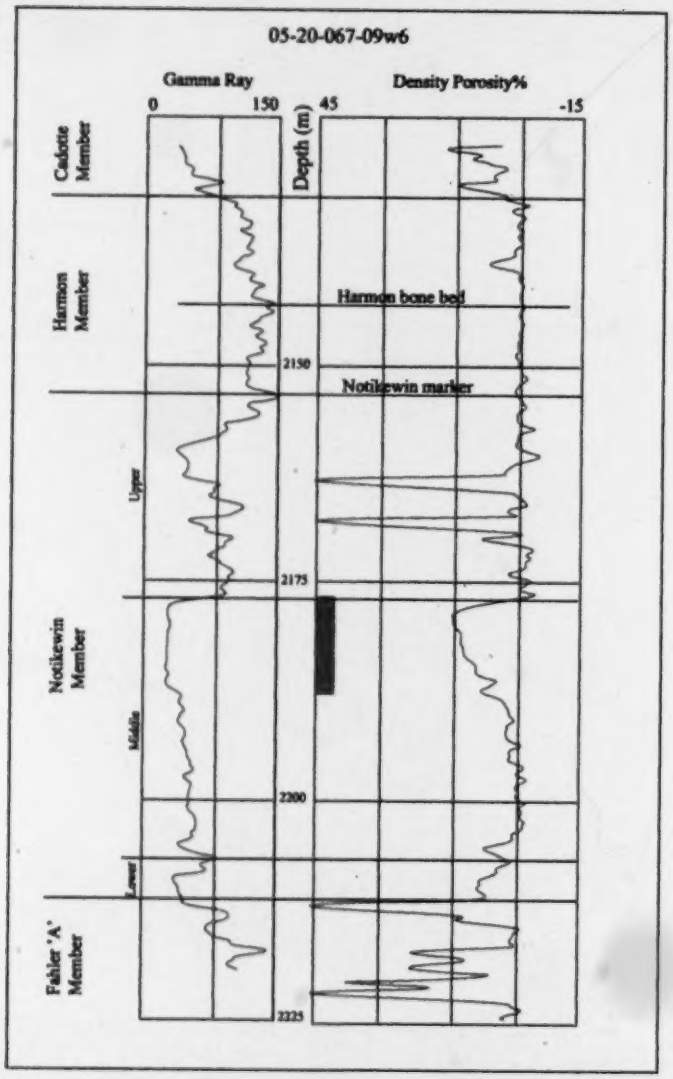



**Figure 1.6. Representative well log signature for the Notikewin in the study area. Possible datum - markers are the "Notikewin marker"; a radioactive unit at the Notikewin-Harmon contact, or the Harmon bone bed. Cored interval is indicated with a solid rectangle in the density porosity column.**

in radioactive shale material interpreted to be a result of transgression that causes a shift to the fully marine environment of the Harmon Member conformably overlying the Notikewin (Smith, 1984). Markers that can be used for stratigraphic datum purposes are the highly radioactive shale at the top of the Notikewin Member or a similar bed in the middle of the Harmon shale. This bed in the Harmon shale, previously recognized as a bone bed with abundant shell material of marine organisms may represent a maximum flooding surface (Saunders *pers comm.*, 1999).

**Palaeogeography:**

The Albian stage of the Early Cretaceous period spans a period from 112 to 98.5 mya. Paleogeographic reconstruction during this time is complicated by differential basinal subsidence, eustatic sea-level changes, and variable orogenic activity. A progressive shift from continental to marine sediments can be seen during the Early Cretaceous. This is represented by the succession from Cadomin to Gething continental deposits and Bluesky to Moosebar marine deposition.

The thick shale sequences of the Moosebar-Wilrich-Clearwater seaway end the transgressive cycle. The seaway inundating the continent at this time was boreal in origin (Figure 1.7), and transgressed as far south as Calgary (Jeletzky, 1971). After deposition of these marine deposits, the pre-Cretaceous erosional topography was compensated for, resulting in a generally flat lying surface on which successive formations would be deposited.

The Falher Member represents deposition in a continental to shallow marine environment with prograding shorefaces being capped by coal deposits. Subsequent deposition of the Notikewin is represented by a shift to a dominantly marine environment. These deposits have been interpreted as a delta to barrier bar environment which progrades from south to north for between 38 and 150 kilometers (Leckie, 1985; Smith *et al.*, 1984). The study area is located within this deltaic to barrier bar environment (Figure

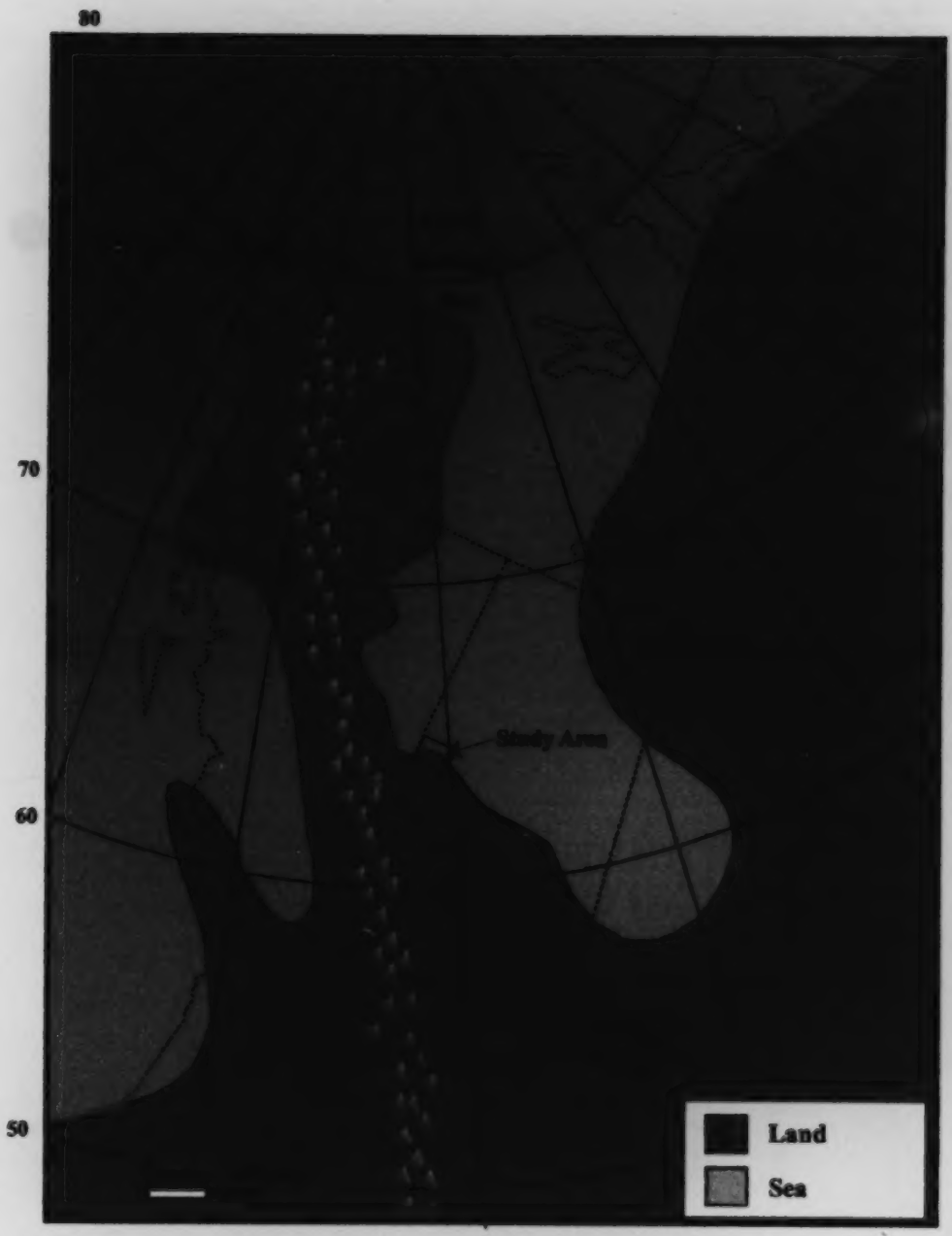



**Figure 1.7. Palaeolatitudes and geographic extent of seaway during Late Early Albian, modified from Jeletzky (1971), Williams and Stelck (1975), and Irving *et al.* (1993).**

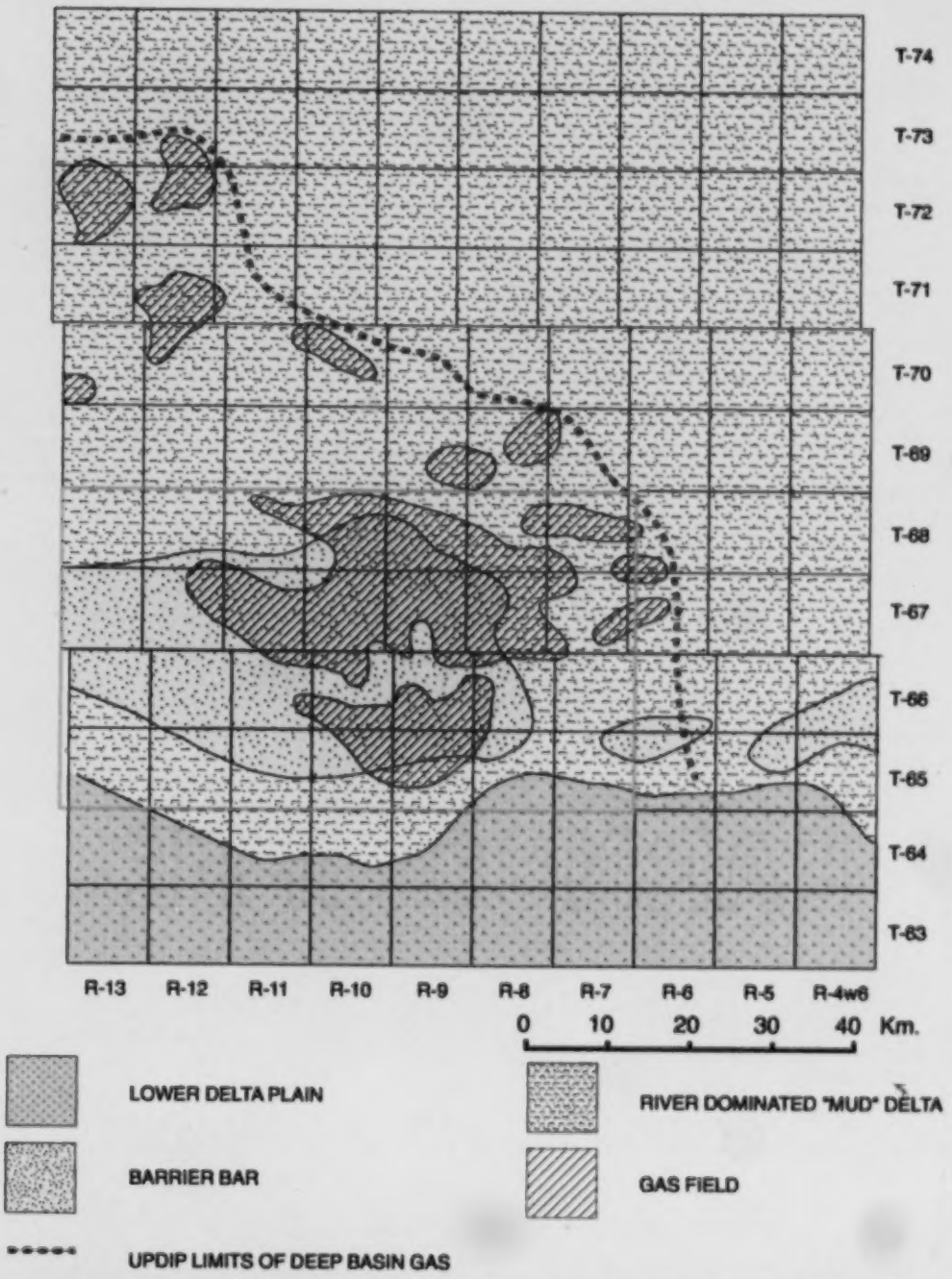



**Figure 1.8. General Palaeogeography of the study area as described by Smith (1984). While this model represents the approximate distribution of sand (barrier bar), other portions are found to be inaccurate, see Chapter 3 for further discussion. Study area is outlined in blue.**

1.8). Farther to the north, the Notikewin is thought to be represented by shelf sands to offshore bars, which give way to open marine shales and silts (Smith *et al.*, 1984).

The end of Notikewin deposition is marked by a transgression of the Clearwater sea. Palaeogeographic reconstructions of areas further east from the Western Canadian Sedimentary Basin Foredeep are difficult due to the post-Mannville unconformity that persists throughout most of Alberta until deposition of the Joli Fou shale.

**Reservoir characteristics:**

Gas pools in the Notikewin occur in the West-Central region of Alberta. Fields to which the Notikewin contributes significant amounts of gas reserves include the Belloy, Fox Creek, Heart River, Karr, Kaybob, Kaybob South, Sinclair, Two Creek, and Wapiti (Figure 1.9). The gas reserves in Figure 1.9 represent proven existing reserves, and do not include future probable discoveries within each field. Smith (1984), who predicted that the member could ultimately contribute 1.5 tcf in the Wapiti field, demonstrates additional potential for the Notikewin.

The Notikewin Member contains several gas fields, however there are no major oil fields discovered as of yet. Unconventional gas fields are found in the Deep Basin in the Wapiti, Karr and Sinclair fields, where water overlies gas. Typical stratigraphic traps occur in other fields further to the east, such as the Belloy, and Heart River.

Economic quantities of gas in the Notikewin have been discovered in sand and conglomerate deposits of barrier bars and offshore bars. Reservoir quality rocks range in thickness from 3.8 meters (Belloy field) to 16 meters (Karr field), with an average of 7.34 meters. (Alberta Energy and Utilities Board, 1997). Porosity in reservoir quality rocks ranged from 7% to 32%. The key factors resulting in reduction of porosity include poor sorting, porosity occlusion by quartz overgrowths, kaolinite and chlorite, and carbonate cementation (Gardiner, 1982).

| Field (Location) | Initial volume in place | | Established reserves | |
|---|---|---|---|---|
| | ($10^6 m^3$) | (bcf) | ($10^6 m^3$) | (bcf) |
| **Belloy (078-01w6)** Notikewin A | 584 | 20.6 | 311 | 11.0 |
| **Fox creek (061-18w5)** Notikewin C | 410 | 14.5 | 312 | 11.0 |
| **Gordondale (079-10w6)** Notikewin B | 109 | 3.8 | 78 | 2.8 |
| **Heart River (077-16w5)** Notikewin | 1800 | 63.6 | 1231 | 43.5 |
| **Karr (065-03w6)** Notikewin D | 776 | 27.4 | 663 | 23.4 |
| **Kaybob (064-19w5)** Notikewin G | 16754 | 591.7 | 13433 | 474.4 |
| **Kaybob South (060-18w5)** Notikewin B | 97 | 3.4 | 58 | 2.0 |
| **Sinclair (074-12w6)** Notikewin A | 222 | 7.8 | 134 | 4.7 |
| **Two Creek (063-16w5)** Notikewin A | 819 | 28.9 | 590 | 20.8 |
| **Wapiti (067-10w6)** | | | | |
| Notikewin A | 442 | 15.6 | 338 | 11.9 |
| Notikewin D | 800 | 28.3 | 578 | 20.4 |
| Notikewin G | 529 | 18.7 | 405 | 14.3 |
| Notikewin H | 729 | 25.7 | 527 | 18.6 |
| Notikewin I | 729 | 25.7 | 527 | 18.6 |
| Notikewin J | 553 | 19.5 | 353 | 12.5 |
| Notikewin L | 449 | 15.9 | 325 | 11.5 |
| Notikewin M | 453 | 16.0 | 327 | 11.5 |
| Total Notikewin in Wapiti area: | 5137 | 181.4 | 3707 | 130.9 |

**Figure 1.9. Estimated reserves for Notikewin gas fields in Alberta (Alberta Energy and Utility Board, 1997).**

# CHAPTER2:

## FACIES DESCRIPTIONS AND INTERPRETATIONS

In the study area, several lithostratigraphic units are identified based on sedimentologic and ichnologic criteria. These units are subdivided into several commonly recurring facies (Figure 2.1), which have been described in non-genetic terms. Constantly shifting paradigms in the geological community result in renewed interpretations of old strata. As such, it is exceedingly important to separate observations from interpretations so that the data presented here may aid in future studies even in the event of such a paradigm shift.

Several facies were seen to occur only rarely or singularly in the study area. This is not a function of the depositional significance of the unit but rather an effect of the preference of petroleum companies to take core in only reservoir quality units. As such, cores from relatively low energy deposits are sparse.

### FACIES ASSOCIATION 1: Prodelta/offshore transition

Facies association 1 (FA1) consists of two typical and one anomalous facies. The core control of FA1 was relatively poor, as the bulk of the cores in the study area were from more shore proximal sediments.

#### Facies 1a Irregularly interbedded sandstone and shale

Description:

*Sedimentological characteristics*: This facies generally consists of 1 to 40 centimeter thick sandstone layers interbedded with thin shale beds or laminations. Overall, bed thickness is highly variable and displays many erosional contacts. Grain size ranges from lower very fine to fine sandstone, which occasionally fines upwards to a dark organic

| Facies association | Facies | Lithology | | Sedimentary Structures | Ichnofossils | Environment |
|---|---|---|---|---|---|---|
| FA1 | 1a | Irregularly interbedded very fine sandstone and shale | | parallel lamination to hummocky and swaley cross lamination | *Asterosoma, Cylindrichnus, Helminthopsis, Lockeia, Palaeophycus, Planolites, Skolithos, Teichichnus* | offshore transition, prodelta |
| | 1b | Rythmically laminated fine sandstone and shale | | parallel lamination, climbing ripples, convolute bedding, microfaulting, oversteepened bedding. | *Arenicolites, Asterosoma, Helminthopsis, Planolites, Scolicia, Thalassinoides* | distal delta front to prodelta |
| | 1c | Intensely bioturbated silty shale | | bioturbated | *Cylindrichnus, Planolites, Skolithos, Teichichnus* | offshore |
| FA2 | 2a | Hummocky to swaley cross laminated fine sandstone | | hummocky and swaley cross lamination, massive bedding, | *Conichnus, Skolithos, Bergaueria, Ophiomorpha,* "Paramacaronichnus", *Palaeophycus* | lower shoreface storm deposits |
| | 2b | Intensely bioturbated fine sandstone and shale | | parallel lamination, bioturbated. | *Asterosoma, Conichnus, Cylindrichnus, Palaeophycus, Planolites, Paramacaronichnus, Rosselia, Skolithos, Teichichnus* | lower shoreface fairweather deposits |
| FA3 | 3a | Interbedded sandstone and polymodal conglomerate | subfacies 3a1: Medium to coarse fining upward sandstone | trough cross bedding, low angle planar, rare current ripple lamination. | *Conichnus,* fugichnia, *Macaronichnus, Skolithos* | uppershoreface waning storm energy deposits, rip channel deposits. |
| | | | subfacies 3a2: Polymodal conglomerate | trough cross bedding, low angle planar bedding | none observed | upper shoreface, storm emplaced deposits |
| | 3b | Bimodal to unimodal granule conglomerate and coarse sand | | low angle planer to high angle bedding. | *Skolithos.* | beach face |

**Figure 2.1. (part 1) facies table.**

| Facies association | Facies | Lithology | Sedimentary Structures | Ichnofossils | Environment |
|---|---|---|---|---|---|
| FA4 | 4b | Ripple laminated to parallel laminated sandstone | trough cross bedding, climbing ripple lamintion, oscillation ripples, planar lamination, mud drapes/couplets, microfaulting, soft sediment deformation | *Conichnus, Cylindrichnus, Diplocraterion, Macaronichnus segregatus, Palaeophycus, Planolites, Skolithos, Teichichnus, Thalassinoides,* root traces | tidal channel, tidal delta, washover |
| | 4a | Bioturbated shale with fine sandstone | lenticular to wavy bedding, planar bedding, convolute bedding, syn-sedimentary faulting, shrinkage cracks | *Asterosoma, Cylindrichnus, Planolites, Chondrites, Helminthopsis, Palaeophycus, Rosselia, Teichichnus, Skolithos, Thalassinoides* , root traces | lagoon, estuary central basin. |
| FA5 | 5a | Non-bioturbated silt and shale | planar bedding, convolute bedding, soft sediment deformation, microfaulting, mud cracks | possible diminuitive *Planolites* and *Skolithos,* root traces | delta plain, lake, pond, abandoned channel fill |
| | 5b | Planar laminated to massive sandstone. | small scale trough cross bedding, planer bedding, massive bedding, rip up clasts | root traces | Fluvial channel, dunes |
| | 5c | Polymodal angular conglomerate | massive | none | Basal fluvial channel, bank collapse. |
| | 5d | Coal | parallel bedding | root traces | Marsh |

**Figure 2.1. (part 2) facies table.**

shale in complete sequences (Figure 2.2A,C). Otherwise the sandstone beds may be amalgamated with numerous internal erosion surfaces. Most often, beds exhibit low-angle planar lamination with occasional oscillation ripples. Pyrite occurs as an accessory within the shale layers. Amalgamated sand layers increase in overall thickness upwards as shale beds become less abundant.

The facies grades upward into fine grained sandstone of Facies Association 2. The lower contact is observed in only 2 of the cores in the study area. In one, it erosionally overlies continental deposits of the Falher member. The other occurrence is as a thin unit overlying coarse sands and gravels of Facies Association 3. This facies was recognized in 5 cores within the study area and ranges in thickness from 20 centimeters to 6.4 meters.

*Ichnological characteristics*: Trace fossils in this interval are sparse and low in diversity. Traces are most commonly found near bedding contacts between the shale and the sand. Trace fossil abundance generally increases upwards until it is truncated by a sharp surface (Figure 2.1 C) Trace fossils include *Asterosoma* (rare), *Cylindrichnus* (rare), *Helminthopsis* (rare), *Lockeia* (rare), *Palaeophycus* (rare-moderate), *Planolites* (rare-moderate), *Skolithos* (rare), and *Teichichnus* (rare).

Interpretation:

Facies 1a is interpreted to represent deposition in an offshore setting dominated by storm and wave conditions. Episodic sedimentation is shown to be frequently the result of major storms or hurricanes (Pemberton *et al.*, 1992). In Facies 1a, event deposits are indicated by the numerous and irregular bedding contacts, and the increased upwards abundance of trace fossils with final truncation of burrowed layers.

This episodic sedimentation is interpreted as a result of deposition dominantly during storm and post storm recovery events, which indicate alternating slow and rapid deposition with erosion (Howard, 1975). The low diversity and sporadic distribution is

**Figure 2.2 Offshore deposits with lesser deltaic influence (Facies 1a,c).**

**A)** 16-31-067-07W6, depth 2004.8m: Interlaminated sandstone and mudstone with varying burrow intensity. Burrowed horizons contain diminutive *Planolites* (Pl), *Cylinidrichnus* (Cyl), and *Helminthopsis (He).*

**B)** 11-19-067-10W6, depth 2406.4m: Photo of anomalous facies (f1c) consisting of intensely bioturbated silty mudstone. Traces include *Teichichnus* (Te), and *Planolites* (Pl).

**C)** 11-30-068-08W6, depth 1944.8m: Interlaminated to interbedded fine sandstone and mudstone. The repeated fining upwards sequences with minimal erosion at the base of the photograph suggest a rhythmic sedimentation pattern. Truncated burrows such as *Cylindrichnus* (Cyl) and erosionally based beds indicate episodic sedimentation such as caused by tempestite deposition. Other burrows include *Asterosoma* (As), diminutive *Planolites* (Pl), and bivalve resting traces; *Lockeia* (Lo).

A
T.R.G.

B
T.R.G.

C
T.R.G.

characteristic of an environmental setting dominated by episodic deposition (Pemberton *et al.*, 1992). Shale deposition is likely representative of post storm settling of fines, or normal fairweather deposition. Some rhythmic sedimentation (Figure 2.2c) indicates that there may have been a small degree of deltaic influence on the system.

Similarly, the general paucity of traces seems to indicate that there may have been other stresses acting on the system. Even in strongly storm dominated systems there is generally much more thorough bioturbation (MacEachern, 1994). The extremely low abundance of traces may suggest stresses such as salinity contrasts, which would be more prevalent in a deltaic system. Although there may be some evidence of such influence, this facies is generally dominated by storm and wave processes.

**Facies 1b: Rythmically laminated fine-grained sandstone and shale**

Description:

*Sedimentological characteristics*: This facies consists of lower to upper fine grained sandstone inter-laminated with 5 to 10 percent shale and organic matter. Laminations are generally horizontal to subhorizontal. Individual beds range in thickness from less then a centimeter to a few centimeters in thickness, with mud content decreasing upwards in the sequence. Though somewhat variable, the beds are markedly more rhythmic in appearance then those of Facies 1a.

Soft sediment deformation includes over-steepened bedding, micro-faulting and convolute bedding. Gas escape structures associated with organic debris are common (Figure 2.4 C). Abundant wood fragments and organic debris occur along bedding planes (Figure 2.4 B). Salinity fluctuations are indicated by the presence of rare syneresis cracks. Facies 1b is recognized in only one well within the study area (06-16-068-11W6). The observable portion is 10.4 meters in thickness and coarsens upwards from a silty shale near the base of the core. The lower contact was not observed due to the limited length of the core. From comparison with well log data, this is likely representative of

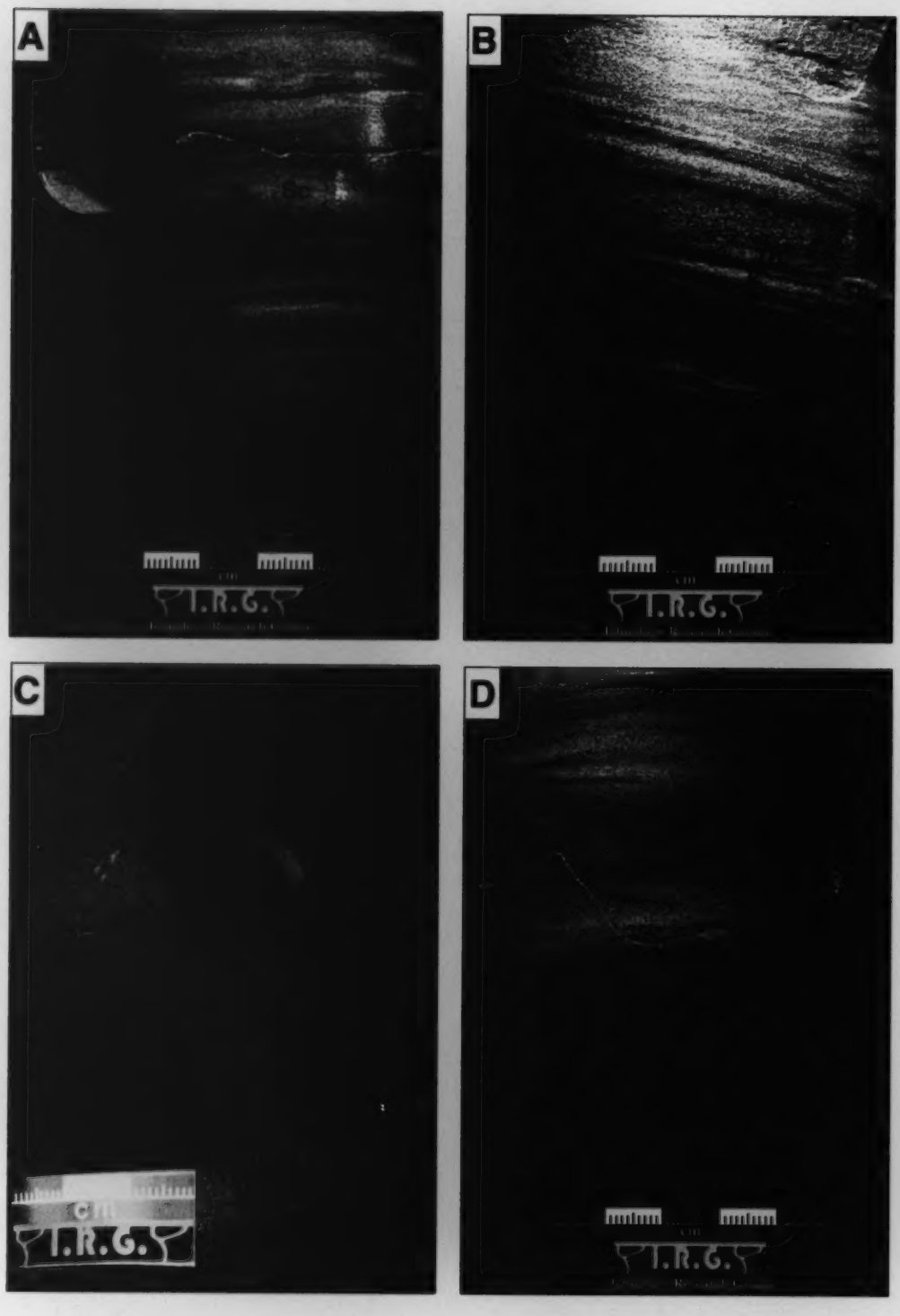
**Figure 2.3 Trace fossils of Facies 1b: distal delta front.**

**A)** 06-16-068-11W6, depth 2220.2 m: Ripple laminated to undulatory low angle laminated mud and fine sand with *Scolicia* (Sc).

**B)** 06-16-068-11W6, depth 2218.8 m: Ripple laminated very fine sandstone with mudstone. Oversteepened and convolute bedding, bioturbated with *Thalassinoides* (Th), and *Asterosoma* (As).

**C)** 06-16-068-11W6, depth 2217.0m: Dominantly fine planar bedded sandstone with minor organic matter containing branched *Thalassinoides* (Th).

**D)** 06-16-068-11W6, depth 2216.0m: Ripple laminated sandstone and shale, bioturbated with *Arenicolites* (Ar), *Planolites* (Pl).


A
B
C
D
I.R.G.

nearly the entire thickness of the unit. Lower shoreface deposits of Facies Association 2 erosionally overly this facies.

*Ichnological characteristics*: Although trace fossils are not abundant, and are of low diversity, they are relatively evenly distributed throughout the succession. This helps differentiate this Facies from Facies 1a. Bioturbation consists of *Arenicolites*, (rare), *Asterosoma* (rare), *Helminthopsis* (rare), *Planolites* (moderate), *Scolicia* (moderate to common) and *Thalassinoides* (moderate) (Figure 2.3 A-D).

Interpretation:

Depositional structures in Facies 1b indicate that sedimentation was dominated by traction and gravity processes. The presence of over-steepened bedding, degassing (or de-watering), and deformed bedding indicate that sedimentation rates were high. The relatively even distribution of such structures attests to the continuous nature of deposition. Similarly, the sparse but evenly distributed burrows are indicative of rapid continuous deposition. The presence of syneresis cracks is indicative of fluctuating salinity levels such as would be found in environments with varying fluvial input. Abundant organic debris and wood fragments similarly attest to the continental source of much of the sediment. Overall the traces are representative of an assemblage of impoverished deposit feeders of the *Cruziana* ichnofacies. The ichnological record displayed here suggests rapid, but generally constant sedimentation.

Wave generated structures such as oscillation ripples are generally lacking, indicating a relative lesser importance of marine processes when compared with Facies 1a. Similarly, there is a general absence of truncated depositional units, indicating that storm processes were of lesser importance. The sediments of Facies 1b are interpreted to represent deposition in a distal delta front to pro delta environment where there is a

**Fig 2.4 Physically generated structures and lithology of Facies 1b.**

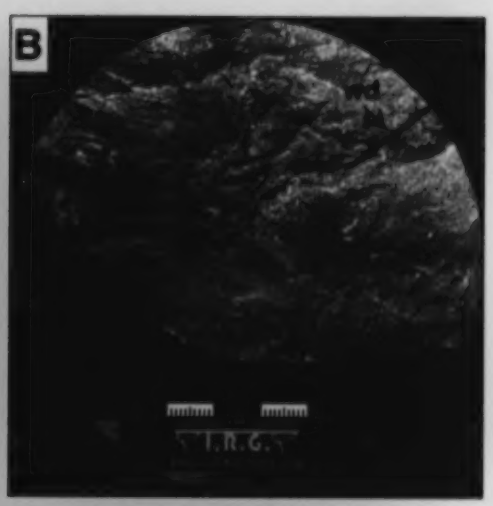
**A)** 06-16-068-11W6, depth 2223.2m: Ripple laminated sandstone and shale with climbing ripple lamination in the upper portion of the photograph, indicating dominance of unidirectional current and high sediment load. Note presence of de-gassing or de-watering structure (dg).

**B)** 06-16-068-11W6, depth 2219.2m: Bedding plane with abundant wood fragments (wd).

**C)** 06-16-068-11W6, depth 2220.2m: Inter-laminated fine sand and mud. De-gassing structure (dg) is seen to originate from decomposed organic matter (org) at the base of the structure.

**D)** 06-16-068-11W6, depth 2217.2m: Interlaminated fine sandstone and shale. Syneresis cracks (syn) indicate fluctuating salinity. Bioturbation consists dominantly of diminutive *Planolites* (Pl).

A
I.R.G.


B
I.R.G.

D
I.R.G.

C
I.R.G.
Technology Research Group

relative dominance of river processes.

**Facies 1c: Intensely bioturbated silty shale**

Description and Interpretation:

One anomalous facies consisting of intensely bioturbated silty shale is recognized in one of the cores examined in the study area. It is 30 centimeters thick and is a single interbed within facies 2a (lower shoreface deposits). Due to the degree of biogenic reworking, physical sedimentary structures are not preserved. Trace fossils observed in this facies include *Teichichnus, Cylindrichnus, Skolithos*, and *Planolites*. This facies is interpreted as representing upper offshore sedimentation during fairweather conditions. It is dominated by the presence of deposit feeding organisms which are characteristic of the *Cruziana* ichnofacies (MacEachern and Pemberton, 1992). In typical offshore settings, diversity would be much higher than is indicated by the 4 ichnogenera recognized here.

Due to the lack of data the description of this facies is considered to be incomplete. A possible interpretation could be that this is an isolated fairweather deposit formed in a sheltered area behind a bar.

Discussion:

It is not always easy to conveniently fit depositional sequences into the general labels of "delta" or "shoreface". The terms are somewhat misleading, as the two environments co-exist with each other along any given coast and it is difficult to determine where one ends and the other begins.

Previous authors have suggested that wave dominated deltas are better considered as shorefaces, since the bulk of sediment is supplied by longshore transport (Reading and Collinson, 1996). Along a deltaic coastline the degree of sediment reworking by waves will vary depending on proximity to fluvial input, intensity of wave and tidal energy, coastline configuration, and composition of bedload. Moslow and Pemberton (1988)

proposed that distinct features indicative of the processes involved in deposition could separate the two settings. Shoreface deposits were described as dominated by episodic sedimentation and oscillatory flow (storm and wave processes respectively), while deltaic environments are generally represented by rhythmic events dominated by suspension, traction and gravity processes together with wave processes. Facies association 1 can be interpreted as an example of the application of this classification.

Although the facies 1a and 1b were found in few cores, they are extremely useful in determining the palaeogeographic configuration of the Notikewin. The presence of Facies 1B westward of facies FA indicates that there may have been a sediment source such as a channel in the western portion of the study area. See chapter 3 for further discussions of the palaeogeographic implications of these deposits.

**FACIES ASSOCIATION 2, lower shoreface deposits:**

Facies association 2 (FA2) is comprised of 3 facies; parallel laminated sparsely bioturbated sand, heavily bioturbated fine sand and mud and inter-laminated sand and mud. It occurs in at least 2 distinct sequences within the Notikewin Member, however in locations far from the palaeoshoreline, the division between these sequences may not be recognizable.

Within the following two facies, a trace fossil which is similar in appearance to *Macaronichnus* is found. There are several features of the trace fossils in this facies that helps to differentiate it from other forms. It is larger in diameter (up to 1 centimeter) and displays a poorer segregation of minerals between the rock matrix and the burrow fill. It also frequently occurs with other trace fossils. For these reasons, it is identified as "Paramacaronichnus", a term that has not yet been formally defined but is useful in this case to facilitate interpretation of the rock units.

**Facies 2a: Hummocky to swaley cross laminated sandstone**

Description:

*Sedimentological characteristics*: The first and most common facies consists of lower very fine to upper fine grained sandstone with low angle parallel laminations. This facies displays numerous internal erosional surfaces that truncate beds, amalgamating them into bed sets of up to 20 meters in thickness. In general most sequences are less than10 meters thick. Thicker sequences are farther basinward and likely represent amalgamation of 2 or more separate sequences.

The sandstone is dominantly quartz with some chert and disseminated organic matter, which help to define laminations. When the sand is more quartz rich, it often appears massive. On close examination some laminations may be present. These laminations appear to have a fuzzy appearance. Ferrigenous mud pellets up to 2 millimeters in diameter are locally abundant and are present in layers along bedding planes and between laminations. Pebbles are also present in thin bands or as isolated occurrences dispersed within the sand (Figure 2.5a,b). These pebble bands typically are more common in the upper portion of a given succession. Rare shale laminations or bands generally less then a centimeter in thickness are observed near the top of bed sets. Frequently, portions of the sand have been sideritized in horizontal bands.

*Ichnological characteristics*: Bioturbation is extremely rare and consists of isolated occurrences of *Conichnus, Skolithos, Bergaueria, Ophiomorpha,* "Paramacaronichnus", and *Palaeophycus*. Often several meters of this facies are observed with no evidence of bioturbation whatsoever.

Interpretation:

Deposits of Facies 2a are interpreted to represent moderately to strongly storm dominated deposits of the lower to middle shoreface. Storm deposits have been extensively discussed in the literature (Hayes, 1967; Leckie and Walker,1982; Bourgeois and

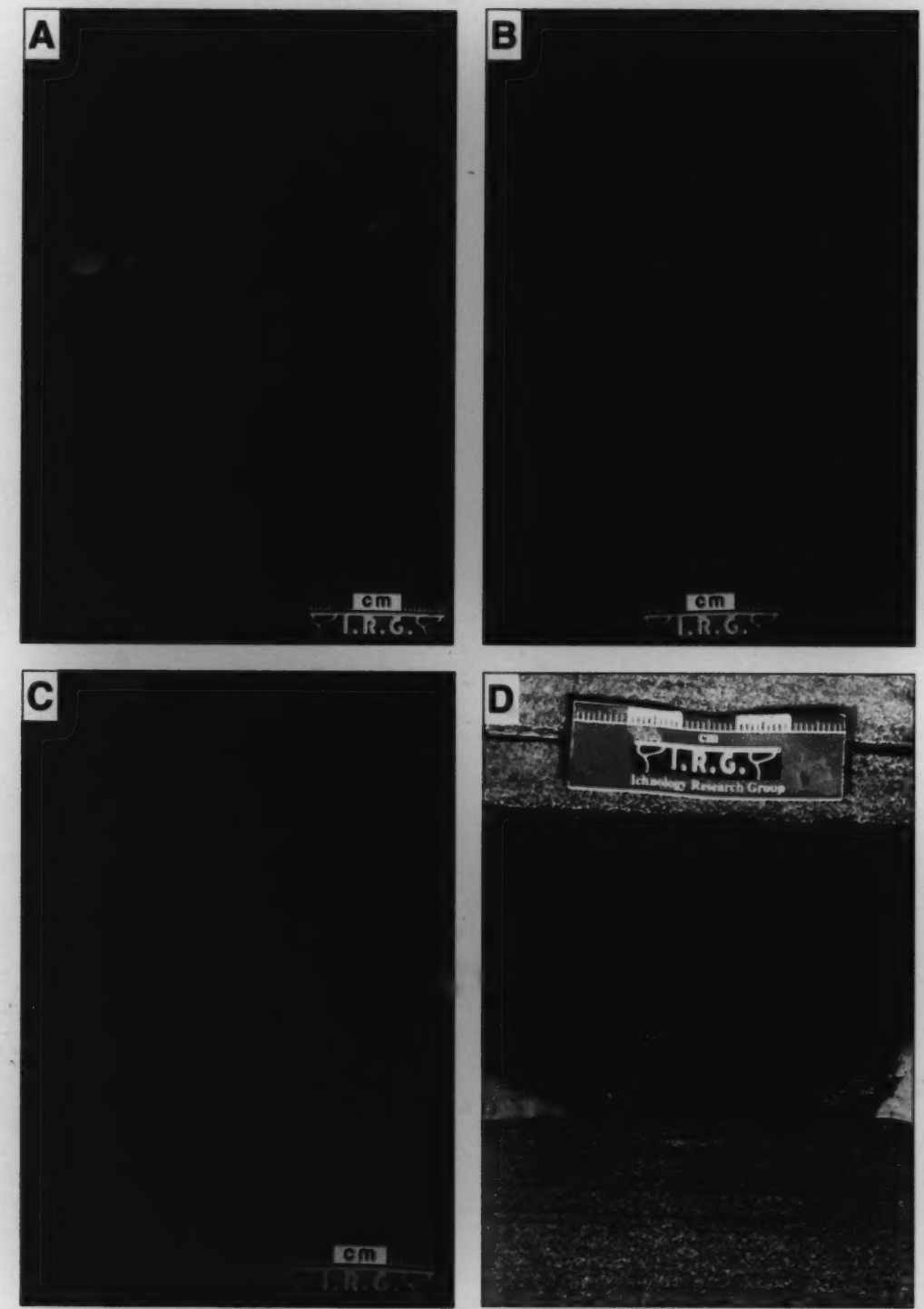
**Figure 2.5 Lower shoreface deposits**

**A)** 01-11-067-12w6, depth 2474.2m: Hummocky or swaley cross stratified sandstone with pebbles occurring as a thin layer and interspersed in the sand matrix.

**B)** 10-16-067-12w6, depth 2494.2m: Well defined hummocky cross stratification, with truncated hummocks displaying characteristic thinning of overlying beds over the crest.

**C)** 07-35-067-10w6, depth 2163.6m: Massive appearing sand, possibly indicating bioturbation by meio-fauna with a resultant destruction of original bedding.

**D)** 13-02-068-07w6, depth 1904.5m, Rare shale layer between typical lowershoreface sands.


A
cm
I.R.G.
B
cm
I.R.G.
C
cm
I.R.G.
D
cm
I.R.G.
Ichnology Research Group

Leithold, 1984; Aigner, 1985; Nummedal and Swift, 1987; Johnson and Baldwin, 1996). The ichnology of these deposits have also been discussed in detail (MacEachern and Pemberton, 1992; Pemberton *et al.*, 1992)

There is much confusion as to what range the shoreface extends. The shoreface has been described in several different fashions. These include; the zone lying below the surf zone but above the inner shelf (Niedoroda et al., 1985), the zone from where waves first break, up until the lower limit of the swash zone (Bourgeois and Leithold; 1984), and as the zone between fairweather wavebase and the low tide line (Reinson; 1984). More confusion in found over where the internal division of the shoreface lay. For the purpose of this discussion, the lower shoreface is defined as the zone landward of fairweather wave base but below the point where waves begin to break. (Reinson,1984). It is equivalent to the transition zone of Bourgeois and Leithold (1984). The middle shore face extends over the zone of shoaling and breaking of waves (Reinson, 1984).

In weakly storm dominated setting it is possible to differentiate the two different zones based and sedimentary and ichnologic characteristics. Ichnologically, the transition can be noticed by a shift from a dominance of suspension feeding in the middle shoreface to deposit feeding in the lower shoreface (MacEachern and Pemberton, 1992). In strongly storm dominated systems this boundary is not apparent, as it is the fairweather assemblage of trace fossils that define the difference between the two (MacEachern, 1994). High energy and high frequency storm events favor minimal preserved burrowing and it is not uncommon for storm dominated middle shoreface sandstones to show little or no burrowing (MacEachern and Pemberton, 1992). Such is the case in the Notikewin Member where sequences greater then 20 meters in thickness can exist without any identifiable bioturbation. The "fuzzy" appearing laminae may be one of the exceptions to the general lack of bioturbation. Such disturbed bedding has been attributed to meiofaunal burrowing organisms such as copedpods (Rouble and Walker, 1997). This type of bioturbation has been recognized from similar deposits in the Cadotte and has

been termed "cryptic bioturbation" (Saunders *et al.*, 1994). Such a burrow fabric has been only recognized in limited occurrences but may be related to storm deposition.

The low angle planar laminations are interpreted as either swaley or hummocky cross-stratification. Along with quasi-planar (Arnott, 1993) lamination, these bedding types have been interpreted to represent deposition under storm conditions (Leckie and Walker, 1982; Dott and Bourgeois, 1982; Duke, 1985). Careful examination of the bed sets may sometimes allow the differentiation of swaley and hummocky cross stratification in core however this is not possible in the majority of cases.

Pebbles are eroded from the beachface and deposited in the shoreface during storms (Reading and Collinson, 1996). However, there is no physical processes known that can regularly transport pebble sized material into the lower shoreface (Bourgeois and Leithold, 1984). The few pebbles observed in the lower shoreface may represent pebbles dropped from plant debris, which may be concentrated as coarse lags in scours during high energy storm events (Bourgeois and Leithold, 1984). In general, it seems that pebble layers are more common in the upper portions of the sand beds, and may mark the transition from lower to middle shoreface. These pebble bands may also represent transgressive lag deposits. However, it is impossible to correlate the bands between wells. The possibility of the occurrence of these pebbles in the lower shoreface precludes this from being diagnostic criteria for separating the lower and middle shoreface deposits in the subsurface. The potential for inter-fingering of the two similar appearing depositional environments further complicates the potential for the recognition of any boundary between them.

The shale laminations and bands that were observed are not generally considered to represent any temporally significant boundary such as a flooding surface. Instead they are likely due to fallout of fine material which was put into suspension during storms (Allen, 1982), or introduced by river floods (Massari and Parea, 1988). The occasional carbonaceous debris found in the upper portions of these beds may also have been

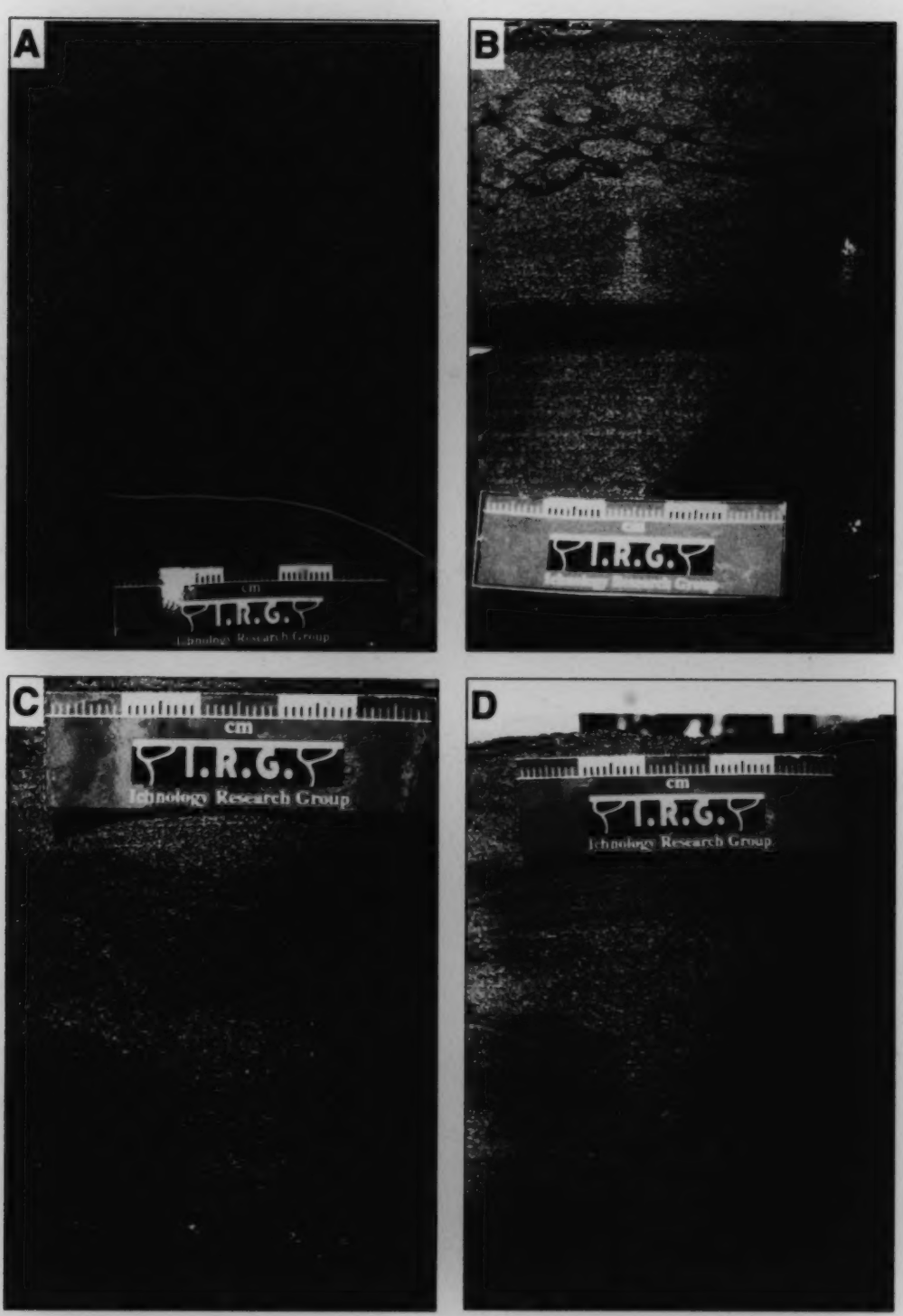
**Figure 2.6 Moderately Bioturbated lower shoreface deposits**

**A)** 7-33-067-08w6, depth 2099.2m: Massive fine sandstone with disturbed burrow, likely a partially disintegrated *Ophiomorpha* (Op).

**B)** 1-23-067-11w6, depth 2419.2m: Parallel laminated fine sandstone with *Palaeophycus* (Pa) and "Paramacaronichnus" (Ma). Similar burrow diameter, and spatial association of traces indicate that these burrows where likely formed by the same tracemaker.

**C)** 1-23-067-11w6, depth 2417.2m: Well developed *Conichnus* (Co) in parallel laminated fine sandstone and shale. Note presence of double mud drapes (md), possibly representing fluctuating energy levels in a tidal or deltaic influenced environment. These sediments were deposited during fairweather conditions, when tidal or deltaic processes would have had a greater influence. The *Conichnus* appears to be re-burrowed with *Palaeophycus.*

**D)** 1-23-067-11w6, depth 2417.3m: *Bergaueria* in parallel laminated fine sand with shale laminations.


A
B
C
D
cm
I.R.G.
Technology Research Group

formed, as organic matter that was washed into the shoreface.

**Facies 2b: Intensely bioturbated fine sandstone and shale**

Description:

*Sedimentological characteristics*: This facies consists of moderately to intensely bioturbated fine sandstone and shale. It occurs in relatively thin layers interstratified with facies 2A, and ranges in thickness from 10 to 50 centimeters. The lower contact is gradational with facies 2A, with bioturbation generally increasing in an upwards direction. The upper contact is sharp and erosive. Internal bedding is generally destroyed by the abundant bioturbation. However, occasional parallel to sub-parallel cross laminated sand and shale can be noticed in the less bioturbated portions. In zones of minimal bioturbation, possible mud drapes are observed (Figure 2.6 c).

*Ichnological characteristics*: Traces include *Asterosoma* (very rare), *Conichnus* (rare to moderate), *Cylindrichnus* (rare to moderate), *Palaeophycus* (common), *Planolites* (common), "Paramacaronichnus" (moderate to common), *Rosselia* (rare), *Skolithos* (moderate) and *Teichichnus* (rare). Thoroughly bioturbated horizons rarely display occurrences of *Conichnus* or *Ophiomorpha* since these traces only occur in the more sparsely bioturbated zones. *Rosselia* and *Asterosoma* only occur in intensely bioturbated horizons with dense populations of *Planolites* and *Palaeophycus*. *Conichnus* is often re-burrowed by tracemakers of *Ophiomorpha* and *Palaeophycus* (Figure 2.6c, 2.7a). Given these relationships, it is possible that *Conichnus* and *Ophiomorpha* are present in the more thoroughly bioturbated horizons but have been re-burrowed to such an extent so that they are no longer recognizable.

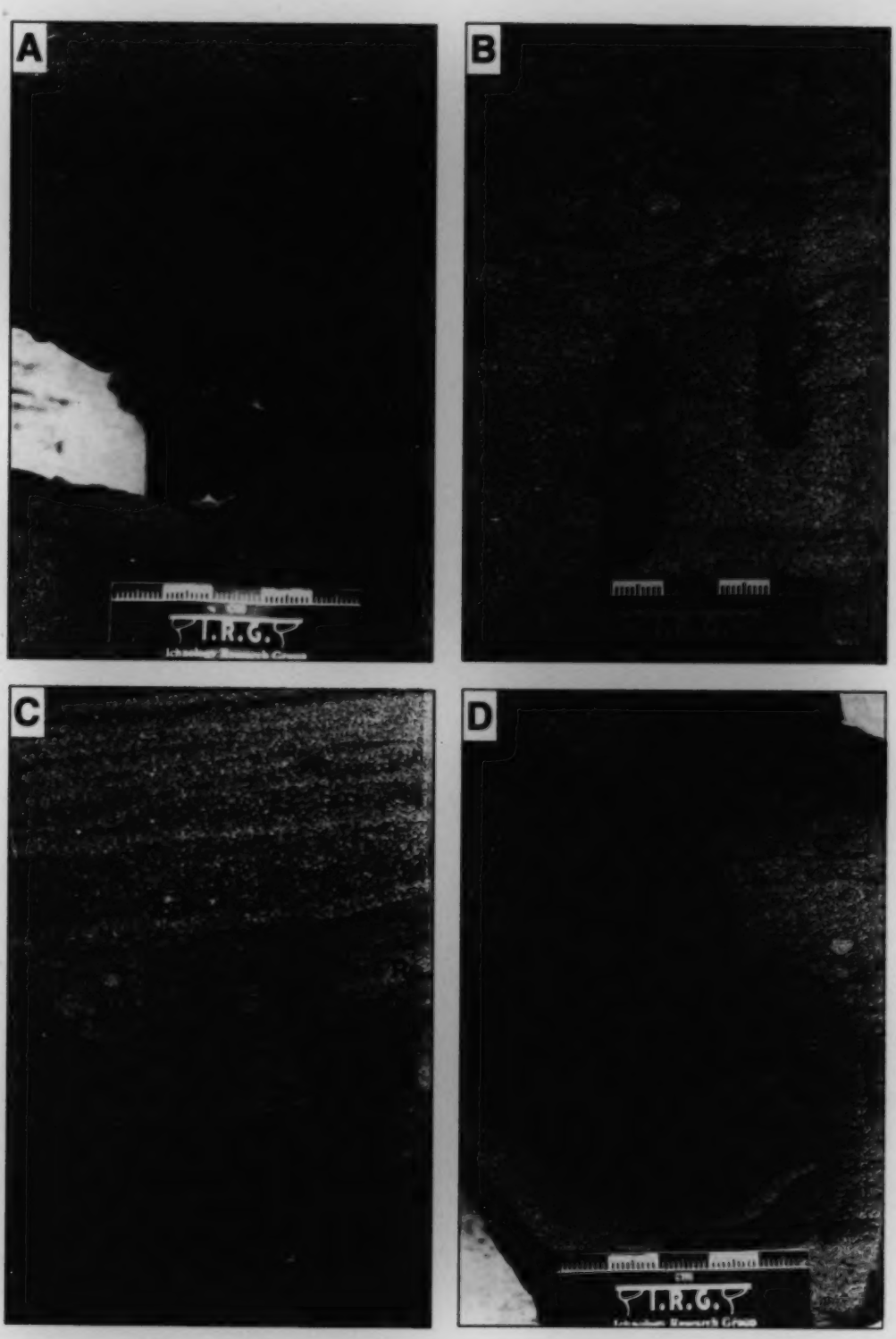
**Figure 2.7. moderate to intensly bioturbated facies 2b**

**A)** 06-27-067-09w6, depth 2116.6m: Lower shoreface fairweather deposits with possible double mud drapes. Initial opportunistic burrows of *Conichnus* (Co) are reburrowed by ambient suite with *Ophiomorpha* (Op), *Palaeophycus* (Pa), and *Skolithos* (Sk).

**B)** 07-33-067-08w6, depth 2099.2m: Parallel laminated to massive fine sand bioturbated with *Diplocraterion* (Di) displaying protrusive and retrusive spreita. The burrow is lined with mud pellets indicating a hybrid behavior likely in response to high energy conditions. The other burrows are "Paramacaronichnus" (Ma).

**C)** 12-16-067-11w6, depth 2371.6m: Laminated to burrowed facies ("lam-scram" bedding style) intensely bioturbated fairweather lower shoreface deposits with *Palaeophycus* (Pa), and *Rosselia* (Ro) overlain with swaley cross stratified storm deposits. Note truncated lower portion of *Rosselia* marking lower boundary of storm bed (dashed line).

**D)** 08-15-067-11w6, depth 2464.2m: Intensely bioturbated sandstone and shale, with *Palaeophycus* (Pa) and other generally indistinct burrows.


A
B
C
D

Interpretation:

Bioturbated horizons make up a relatively small proportion of the lower to middle shoreface. These horizons represent may represent either post storm re-colonization of the substrate or deposition during the summer when storm energy is relatively low. Indications of relatively low energy conditions include the abundance of bioturbation, and the presence of horizontal laminated bedding.

Horizontal shale laminae commonly appear as possible double mud drapes that may be interpreted in two different ways. The first is as tidal couplets; indicating that during fairweather conditions there is tidal influence. Generally, it is impossible to form such structures without some channelization of flow, such as would occur in inter-tidal deposits. Possible tidal structures have been recognized in a wave dominated shoreface environment which were interpreted to represent deposits formed when tidally induced flow was funneled between shoals (Martini *et al.*, 1995). No structures were observed however, that represent complete tidal cycles or reactivation surfaces which are diagnostic for interpreting tidal environments (Nio and Yang, 1991). This facies was limited, therefore the absence of such structures should not be considered definitive. It is possible that there is a greater dominance of tidal influence in preserved summer deposits. Such rhythmic structures may also be formed by episodic influx of fine material from river channels, during flood conditions. This likely interpretation seems more likely and suggests a deltaic origin of these deposits which are, consistent with interpretations of FA1.

The initial post storm colonization is marked by the appearance of traces that are interpreted to represent the burrows of opportunistic tracemakers. Opportunistic tracemakers are described as organisms able to take advantage of the vacant substrate left by episodic events (MacEachern and Pemberton, 1992). In the Notikewin, these consist of *Conichnus, Ophiomorpha* and *Skolithos*. *Conichnus*, and *Ophiomorpha* tend to exist as the background suite in a bioturbated horizon. The background suite is re-burrowed by

*Asterosoma, Cylindrichnus, Palaeophycus, Planolites*, and *Rosselia*. These ichnogenera represent an equilibrium fauna of the *Cruziana* ichnofacies which follow fairweather re-colonization of the substrate.

In general, the ichnological record of these deposits consists of traces of predominantly deposit-feeding organisms of the *Skolithos* ichnofacies, with few elements of the *Cruziana* ichofacies. In other lower shoreface deposits this has been attributed to the well winnowed nature of the sand in storm deposits. This results in a paucity of food for deposit feeders of the *Cruziana* ichnofacies to feed on (MacEachern and Pemberton, 1992).

Burrows of *Palaeophycus, Planolites*, and "Paramacaronichnus" seem to be somewhat related. They frequently occur together and are approximately the same size, ranging from 0.7 to 1.0 centimeters in diameter (Figure 2.5b). This relationship has been previously noted to occur in lower shore-face sands of the Cadotte Member which were previously thought to be part of the same burrow structure (Saunders *et al.*, 1994). Similar specimens have been found in lower shoreface of the Englishtown Formation (Curran, 1985) and the Bluesky Formation (Brekke and Pemberton, 1994). These large diameter specimens may have a greater affinity for the lowershoreface, although rigorous analysis and comparison with modern analogies is yet required to establish a more reliable relationship. The intimate relations of the three traces in the Notikewin suggest that it is likely that these burrows may have been made by the same tracemaker, and demonstrates the adaptability of the organism to different conditions. "Paramacaronichnus" in the lower shoreface has been thought to have been constructed by some species of orbinid polychaete (Saunders *pers com.*, 2000).

**FACIES ASSOCIATION 3: Upper-shoreface to Foreshore**

Facies Association 3 is divided into 2 main facies; 3a: interbedded sandstone and

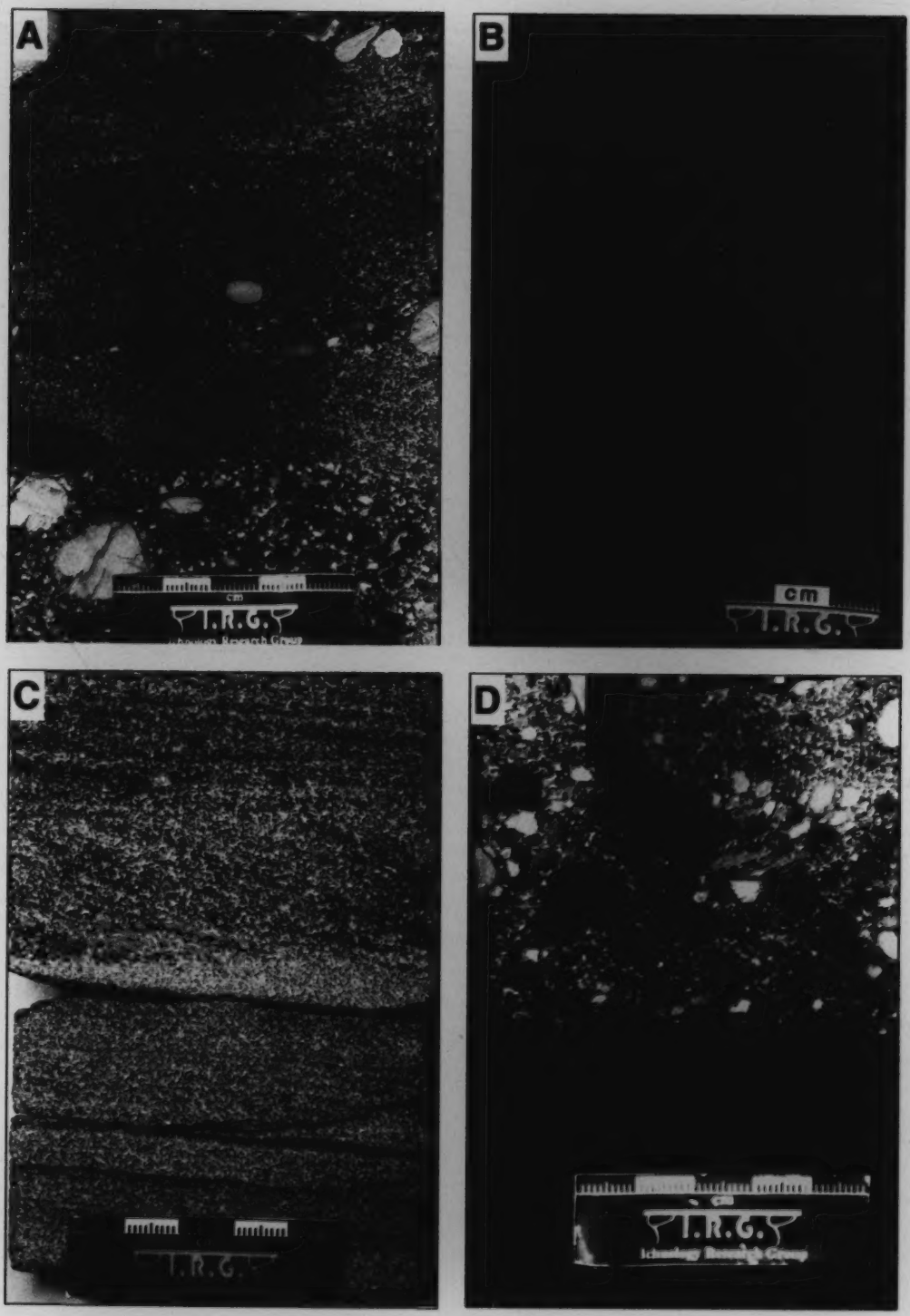
**Figure 2.8 Upper shoreface lithologies and sedimentary structures:**

**A)** 08-15-067-11w6, depth 2461.4m: Trough cross-bedded medium sandstone interbedded with polymodal clast to matrix supported conglomerate.

**B)** 07-35-067-10w6, depth 2152.0m: Trough cross-bedded medium sandstone interpreted to represent deposition from longshore or rip currents in the upper shoreface.

**C)** 06-04-068-07w6, depth 1961.2m: Contact between lower (parallel laminated fine sand) and upper shoreface (trough x-bedded coarse to medium grained sandstone), with trough forsets overlying parallel laminated beds of the lower shoreface. This type of erosional contact is typical of barred shoreface successions.

**D)** 06-27-067-09w6, depth 2115.2m: Another manifestation of the contact between the lower and upper shoreface, this time with conglomerate of the upper shoreface overlying fine grained sandstones of the lower shoreface.


A
B
C
D
cm
T.R.G.

conglomerate, and 3b bimodal to unimodal granule conglomerate and coarse sandsone. Facies 3a is further sub-divided into 2 subfacies; 3a1: fine-grained to coarse-grained sandstone, and subfacies 3a2; polymodal conglomerate. The most common occurrence of these facies is seen in inter-bedded elements of facies 3a1 and 3a2, that give way upwards to a greater predominance of facies 3a2. Facies 3a is most commonly overlain by facies 3b. In other occurrences, either or both of facies 3a2 and 3b may be missing.

**Facies 3a: inter-bedded sandstone and polymodal conglomerate**

Subfacies 3a1: fine to coarse grained sandstone

Description:

*Sedimentological characteristics*: This facies consists of lower fine grained to coarse-grained sand, though it is dominantly upper fine-grained. The lowermost occurrence of this facies typically overlies facies association 2 (lower shoreface deposits). This contact is generally sharp and flat, with either conglomerate or sand overlying parallel laminated to swaley fine sand (Figure 2.8c.d). In northerly occurences, the transition is gradational. This facies grades upwards into or is sharply overlain by facies 3b (foreshore deposits).

Subfacies 3a1 is generally well-sorted and individual beds fine upwards. Overall however, there is a coarsening upward relationship. Granules or coarser sand fractions may be either interspersed within the sand or occur as isolated bands that are typically less then a centimeter thick. Sedimentary structures include low angle planar lamination and small to medium scale foresets, or trough cross-lamination. Pebbles are often imbricated along the foreset laminae. Occasional thin beds of shale, up to two centimeters in thickness are rare.

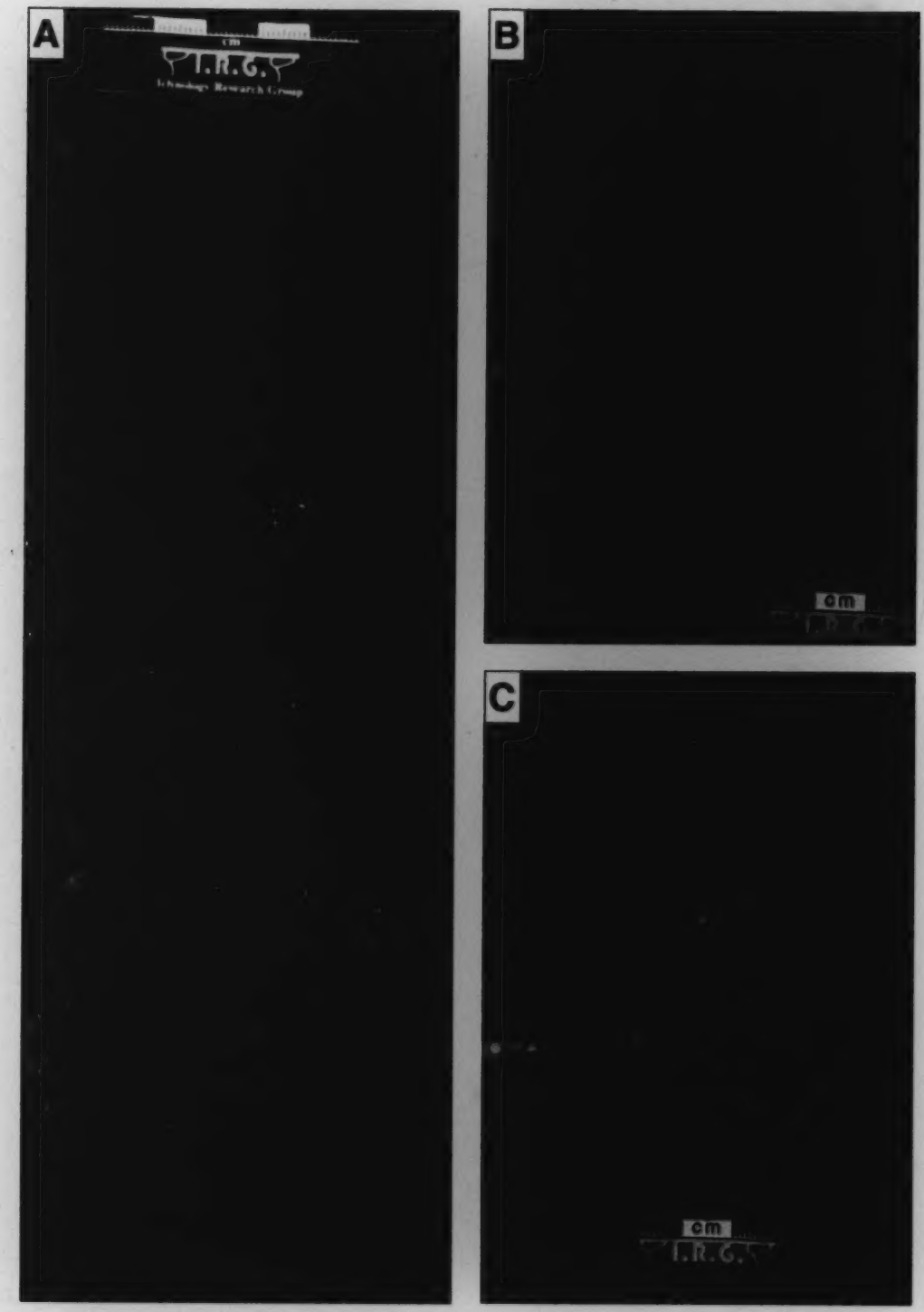
In most occurrences the sand is inter-stratified with polymodal conglomerate of subfacies 3a2 in a bedding style that has been described as sand-gravel couplets (Massari and Parea, 1988). In more northern sequences within the study area it may occur

**Figure 2.9 Upper shoreface Trace fossils**

**A)** 16-31-067-07w6, depth 1999.2m: Sediment disruption due to presence of *Conichnus* (Co) in upper shore face parallel laminated fine sand and mud with occasional scattered pebbles and granules Muddy layers display a possible tidal pattern, indicating that at times, tidal processes may have been important in what is generally a wave dominated system.

**B)** 10-16-067-12w6, depth 2587.6m: Trough cross-bedded fine sandstone intensely bioturbated with *Macaronichnus segregatus*. Despite intense bioturbation, original bedding can still be seen.

**C)** 01-11-067-12w6 depth 2464.7m: Inter-bedded fine sand and matrix supported granule conglomerate, with escape trace (fug).


A
cm
T.R.G.
B
cm
C
cm
T.R.G.

solitarily in thickness of up to 5 meters. When it is inter-stratified with the conglomerate, it ranges from a few centimeters to 3.6 meters. Upwards, layers of sand become thinner and eventually disappear and grade into conglomerate beds. When conglomerate is not present it may be sharply overlain by facies association 4 (lagoonal and tidal channel deposits). In this later situation, there are typically root traces in the upper portion of the beds.

*Ichnological characteristics*: Trace fossil abundance and diversity is typically very low; the exception to this is the extensive occurrences of *Macaronichnus segregatus* that were observed in 20 of the studied cores. These burrows are most common in the uppermost occurrences of the pebbly sandstone beds, and were persistent for intervals of up to 1.5 meters. Typically, *Macaronichnus* was very abundant in relatively small intervals (Figure 2.9b) Other trace fossil elements that were observed were *Conichnus* (rare), *Skolithos* (very rare), *Thalassinoides* (very rare) and fugichnia (very rare). These traces were found only as isolated single burrows in relatively finer grained sediments.

Subfacies 3a2: polymodal conglomerate

Description:

*Sedimentological characteristics*: Subfacies 3a2 consists of a polymodal matrix, to clast supported conglomerate. The matrix is generally upper fine sandstone. Clasts are well rounded and are either spherical or disk shaped. Disk shaped clasts may occasionally show a weak imbrication.

Bedding looks massive with a lack of well defined sedimentary structures, However, this observation is likely due to the limited size of the core. Asymmetric wave ripples are sometimes observed at bedding contacts though the scale of the features when compared to the core diameter prevents a positive identification. Low angle planar bedding may be present (Fig 2.9c). A crude fining upward pattern is common in the

conglomerate. Clast sizes are generally between 0.5 and 1.0 cm, however clasts up to 6 cm in long axis length are occasionally observed. The beds range in thickness from a few centimeters to 90 centimeters.

*Ichnological characteristics*: No distinct trace-fossils where observed in the conglomerate facies.

Facies 3a interpretation:

Facies 3a is interpreted as representing deposition in the upper-shoreface. The upper shoreface is situated between the lower edge of the surf zone and the low tide mark (Clifton *et al.*, 1971). Studies of the upper shoreface are mostly drawn from subsurface examples as the practical difficulties of research in the high energy breaker zone impedes the study of modern counterparts. These deposits are similar to other deposits that have previously been described from the Cretaceous of the Western Canada Sedimentary Basin. These occur in the Cadotte Member (Rahmani and Smith, 1988; MacEachern, 1994; Sauders *et al.*, 1994), Falher Members (Cant, 1984, 1994, 1995; Rouble and Walker 1994, 1997; Arnott, 1994) and the Lower Gates Formation (Leckie and Walker, 1982). Nilsen (1973), Clifton (1981), Bourgeois and Leithold (1983, 1984), Dupré (1984), and Massari and Parea (1988, 1990) have described similar deposits in other areas. Comparable deposits in the Falher Member of the Spirit River Formation have been attributed to several different possible depositional mechanisms.

One of the early suggestions was that these deposits were formed in fluvial or distributary channel systems related to flood and waning flow deposition (Cant, 1984; Arnott, 1994). The evidence cited for the fluvial origin of these deposits is the poor sorting and sharp-based nature of conglomerates, and the fining upward trends of individual beds.

Cant (1994,1995) suggested that similar deposits in the Falher A and B divisions

may indicate deposition in a system of laterally migrating tidal channels developed during transgression. Cant (1994,1995) described evidence for a tidal origin as the sharp bases of the conglomerates, the presence of mud and coal clasts, and the cross-bedding.

Neither of these interpretations adequately explains the facies relationships seen in the Notikewin Member. Alternatively, a wave-dominated upper shoreface environment of deposition is favored for this facies. Similar deposits have been interpreted in this manner and have been extensively described in the literature (Dupré, 1984; Massari and Parea 1988,1990; Bourgeois and Leithold, 1984; Rouble and Walker, 1994, 1997)

In facies 3a, individual beds fine upwards, although the overall trend is one of coarsening upwards, with sandstone beds gradually thinning and with conglomerate beds becoming more frequent. An overall fining upward sequence is generally inconsistent with a fluvial interpretation. In addition, presence of trace fossils such as *Macaronichnus segregatus*, and *Conichnus* suggests a marine environment of deposition. While Cant (1994, 1995) cites the sharp bases as evidence of tidal influence, the erosional bases of the gravel deposits may represent the peak of storm events where gravel is eroded from the beach face and deposited in longshore troughs along the upper shoreface (Dupre, 1984; Masseri and Parea 1988). The poor sorting of similar deposits has been attributed to mass-flow phenomena (Masseri and Parea 1988). Within storm dominated coastal systems, the upper shoreface has been shown to be dominated by strong longshore and rip current activity in the region immediately seaward of the beachface (Hunter *et al.*, 1979). The trough cross-stratified sand overlying these gravels is interpreted to represent the deposition resulting from long shore currents during the waning cycles of storms. Each couplet may represent one complete storm cycle. A tidal interpretation would require lower wave energy then is present in the Notikewin for preservation of tidal channels. Overall, a strong storm and wave imprint on sedimentation is displayed. The rare mud layers may be formed in the last stage of the storm during waning wave energy, or they may be preserved fair-weather deposits. The greater cohesiveness of clay size particles

would facilitate this type of preservation. Although there was some indication of possible tidally generated mud drapes (Fig 2.7a), these structures were not widely recognized. Additionally, the widespread occurrence of the interbedded sands and gravels suggests a more regional influence on sedimentation than tidal channels would provide. Tidal inlets or any type of barrier breaching are rare or absent in strongly wave-dominated depositional sequences (Dickenson *et al.*, 1972). Although tidal energies may have had some influence on deposition during Notikewin time, the overall dominance of storm and wave energies has shaped most of the depositional record. Martini *et al.* (1995) described similar observations of tidal features in a wave-dominated shoreface environment from the Miocene of Italy. These features were attributed to localized effects of funneling flow between shoals.

Rip current processes have been shown to result in a laterally extensive erosional surface between upper shoreface and middle to lower shore face deposits, which is marked by an increase in grainsize above and below the contact (Hunter *et al.*, 1979). Such a surface has been used as evidence for a barred shoreline configuration in the Cadotte (Rahmani and Smith, 1988; Saunders *et al.*, 1994), as predicted by the vertical succession of facies described by Hunter *et al.* (1979). Recently, sharp increases in grain-size have been interpreted as representing a sharp-based shoreface deposited during a forced regression (Rosenthal and Walker, 1987; Plint, 1991; Walker and Plint, 1992; Plint, 1988). Although there is a sharp contrast in grainsize at the lower contact of the upper shoreface sediments seen in the Notikewin, there is no presence of either gutter casts, or mud rip-up clasts that are common features of forced regressive sequences (Walker and Plint 1992; Posamentier and Allen, 1999). In addition, interbedded sandstone and conglomerate are generally preserved in longshore troughs. Longshore bars that are formed during fair-weather conditions have little preservation potential as they migrate land-wards and are welded to the beachface during storms. In storm dominated systems, coarse material is moved landward while fine material remains in suspension and is swept

basinward (Elliot, 1986). These processes tend to accentuate the grain size contrast across the erosional surface. The grain-size variation should therefore be regarded as a result of normal shoreface processes rather then any abrupt sea-level change. In addition, the occasional occurrence of a gradational contact is inconsistent with an interpretation involving abrupt sea level changes.

Because this surface can be more parsimoniously explained by processes inherent to storm dominated shoreface deposition, it should not be interpreted as stratigraphically significant. It indicates that the Notikewin likely had a barred shoreline configuration.

Upper shoreface sediments generally contain elements of the *Skolithos* ichnofacies of suspension feeding organisms (MacEachern and Pemberton, 1992). Overall the ichnological record of the Notikewin sediments reflects very high wave-energy conditions. The traces that are present reflect one of two general behaviors.

The first of these is rapid movement through the sediment to compensate for high deposition rates. This behavior is demonstrated by traces such as *Conichnus* (Fig 3.7a) and fugichnia (fig 3.7c). Such traces fit with an interpretation as belonging to a highly stressed *Skolithos* ichnofacies.

While the Notikewin contains some traces that indicate a suspension-feeding behavior (*Conichnus* and *Skolithos*), the majority of the biological community is dominated by the deposit-feeding behavior of the *Macaronichnus* tracemaker. *Macaronichnus segregatus* is a common element of high-energy shoreface successions (MacEachern and Pemberton, 1992). It is frequently and most abundantly seen to occur at the toe of the foreshore (Saunders *et al.*, 1994), though it has also been reported from a variety of other settings such as, the lower shore face (Curan, 1985), and within tidal channel deposits (Clifton, 1978). Within a particular depositional sequence, it has been shown to preferentially occupy a single environment. Such is the case in the Notikewin where it occurs primarily in the upper-most portion of the upper-shoreface sediments. The behavior reflected by *Macaronichnus* is an attempt to escape high-energy conditions at the

surface by deep burrowing, and by this behavior, the *Macaronichnus* tracemaker separates itself from the surface environment. As such, *Macaronichnus* reflects a fundamentally different behavior than fits in the present ichnofacies concept.

The high wave energy level as indicated by the sedimentary structures and trace fossil content supports a wave dominated depositional environment. Widespread preservation of tidal channels would require a lesser influence of wave processes so it is unlikely that deposits of the upper shoreface reflect a tidal origin. The distributary channel interpretation is also unlikely, as the trace fossil assemblage is indicative of marine conditions.

**Facies 3b: Bimodal to unimodal granule conglomerate and coarse sand**

Description:

*Sedimentological characteristics*: This facies occurs above facies 3a, and is overlain by varied deposits of facies association 4 and 5. It generally occurs in the middle of the Notikewin, but in two cores, it is observed at the base below facies 2a. The lower contact of the unit is typically gradational and may be difficult to pinpoint. The upper contact is sharp when overlain by facies association 4, or sharp to erosive when overlain by facies association 5. Overall thickness is variable and ranges from 0.8 to 7.4 meters.

Facies 3b consists of inter-bedded well-rounded generally spherical pebbles to upper medium grained sand. Most commonly, the sizes range from very coarse sand to granule size. In occurrences at the base of the Notikewin, this facies contained abundant carbonaceous material. The smaller grain sizes are more spherical than pebble size material, which is frequently disk shaped. Disk shaped particles may occasionally show a weak imbrication (figure 2.10b). Individual beds are extremely well sorted, though there is some variation between beds. Beds rarely display any grading, and are a few centimeters to decimeters in thickness. Coarser beds typically occur in the lowermost

portions of the succession. Higher up in the succession, the beds become progressively finer and display greater sorting, typically culminating in a unimodal conglomerate or well-sorted coarse sand.

Conglomerate beds are clast supported, with very little or no fine-grained matrix. This corresponds with a great increase in visible porosity.

Clasts were composed dominantly of chert and quartz, with a small portion of carbonate rock fragments. Typically, beds appear either massive or may display low to high angle bedding surfaces (Figure 2.9 a, d). The apparent lack of bedding in some units may be due to the limited scope of observation in the core, given a typical core thickness of 3 1/2 to 4 1/2 inches).

*Ichnological characteristics*: Bioturbation was very rarely observed in this facies. There are two likely reasons for this. The coarseness of the sediment prevented preservation of the burrows. The other reason is that the burrows are more difficult to discern when there is little grain-size variation between the burrow fill and the matrix. It is therefore likely that present observations of biogenic activity are somewhat underestimated. When observed, the burrows are generally indistinct, though some good examples of *Skolithos* are present (figure 2.10c). In this instance, these burrows are seen to contain material derived from a higher bed, indicating that some of the burrows were maintained as an open system.

Interpretation:

Facies 3b is interpreted to represent deposition in a foreshore environment. The foreshore represents the intertidal portion of a shoreline succession where the sediments are regularly exposed and covered by the daily tides. Wave processes in the foreshore reflect both surf and swash, and thus it is transitional with the upper shoreface.

In finer grained beaches, this produces a distinctive bedding feature known

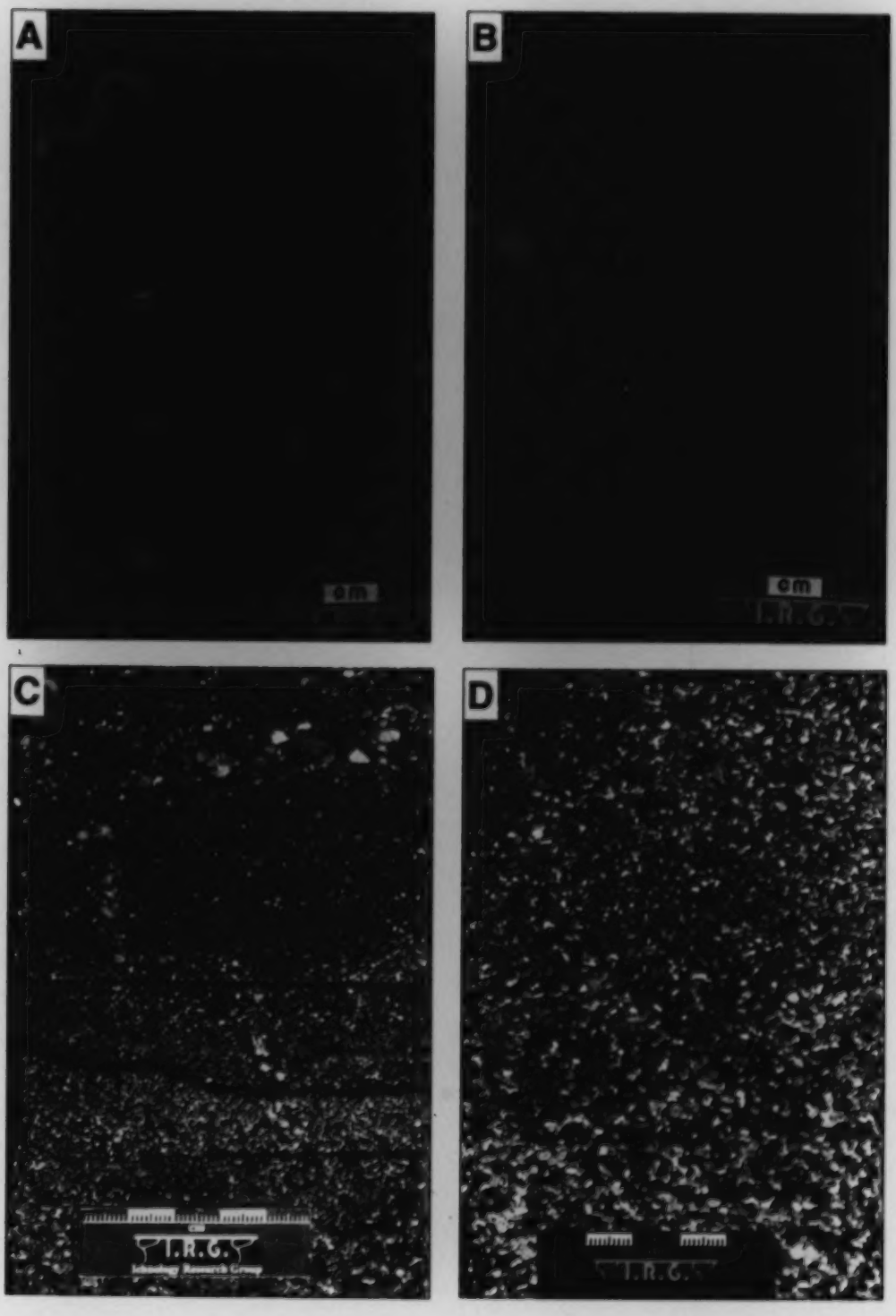
**Figure 2.10 Beach deposits**

**A)** 15-09-067-12w6, depth 2511.0m: Low angle sharp contact between coarse sand and bimodal clast supported conglomerate. Bedding in the foreshore is not generally observed due to the coarseness of the deposit except where the contacts are defined by profoundly different grain-sizes.

**B)** 15-09-067-12w6, depth 2512.0m: Bimodal clast supported conglomerate of the lower beachface displaying imbrication of disk shaped material. Some of the larger clasts may be weakly imbricated.

**C)** 08-15-067-11w6, depth 2453.0m: Unimodal to bimodal granule conglomerate inter-bedded with coarse sand containing *Skolithos* (Sk) that are rarely preserved in this facies. Burrows are infilled with sediment from overlying layer indicating that the burrows were open, and were passively filled. Such surfaces do not have the temporal significance of a *Glossifungities* discontinuity, as sand does not require the same degree of burial as mud to become cohesive.

**D)** 08-15-067-11w6, depth 2452.2m: Unimodal granule conglomerate, displaying well-rounded clasts and good porosity. This is typical of good reservoir facies in the Notikewin.


A
B
C
D
T.R.G.
Technology Research Group

as swash-zone stratification (Elliot, 1986). In the Notikewin, the coarseness of the deposit prevents the formation of such fine bedding features. The relatively steep angle bedding that is preserved is likely due to migration of ridge and runnel systems. During fairweather conditions, the ridges will migrate landwards, and weld themselves to the berm. Ridge and runnel stratification is rarely observed in the ancient record but is quite a common feature in the modern (Vos and Hobday, 1977). Ridge and runnel systems are preserved primarily in post storm or relatively calm summer conditions, since storm conditions result in the destruction of such features (Vos and Hobday, 1977). This type of stratification may explain the relatively rare higher angle bedding contacts noted in the conglomerate. During storm conditions, low angle planar stratification of the upper flow regime are generally formed (Vos and Hobday, 1977).

The lowermost portion of the sequence, recognized by the presence of a thick and poorly sorted conglomerate is interpreted as the depositional record of the plunge-step. This is a coarse grained feature created by breaking waves at the base of the beachface (Massari and Parea, 1988; Reading and Collinson, 1996). This feature has also been recognized in other Spirit River Cycles (Rouble and Walker, 1994,1997).

The thickest portions of the deposits are interpreted to represent a storm berm, or storm ridge. The thickness of the deposits is consistent with that of other gravel beaches. Kirk (1980) noted that such deposits could reach up to 14 meters in thickness. There can be several of these ridges within a single depositional sequence (Kirk, 1980). This could certainly be possible in the Notikewin, although it would be difficult to determine without greater drilling and core density.

Due to the coarseness of the deposit, trace fossils are not well preserved. In addition, the trace fossils that are present are difficult to see since they take the form of simple unlined vertical tubes (*Skolithos*), with the burrow fill generally of the same composition as the matrix. It is likely that sediments have undergone far more biogenic reworking then is apparent. However there is relatively little bioturbation in beach

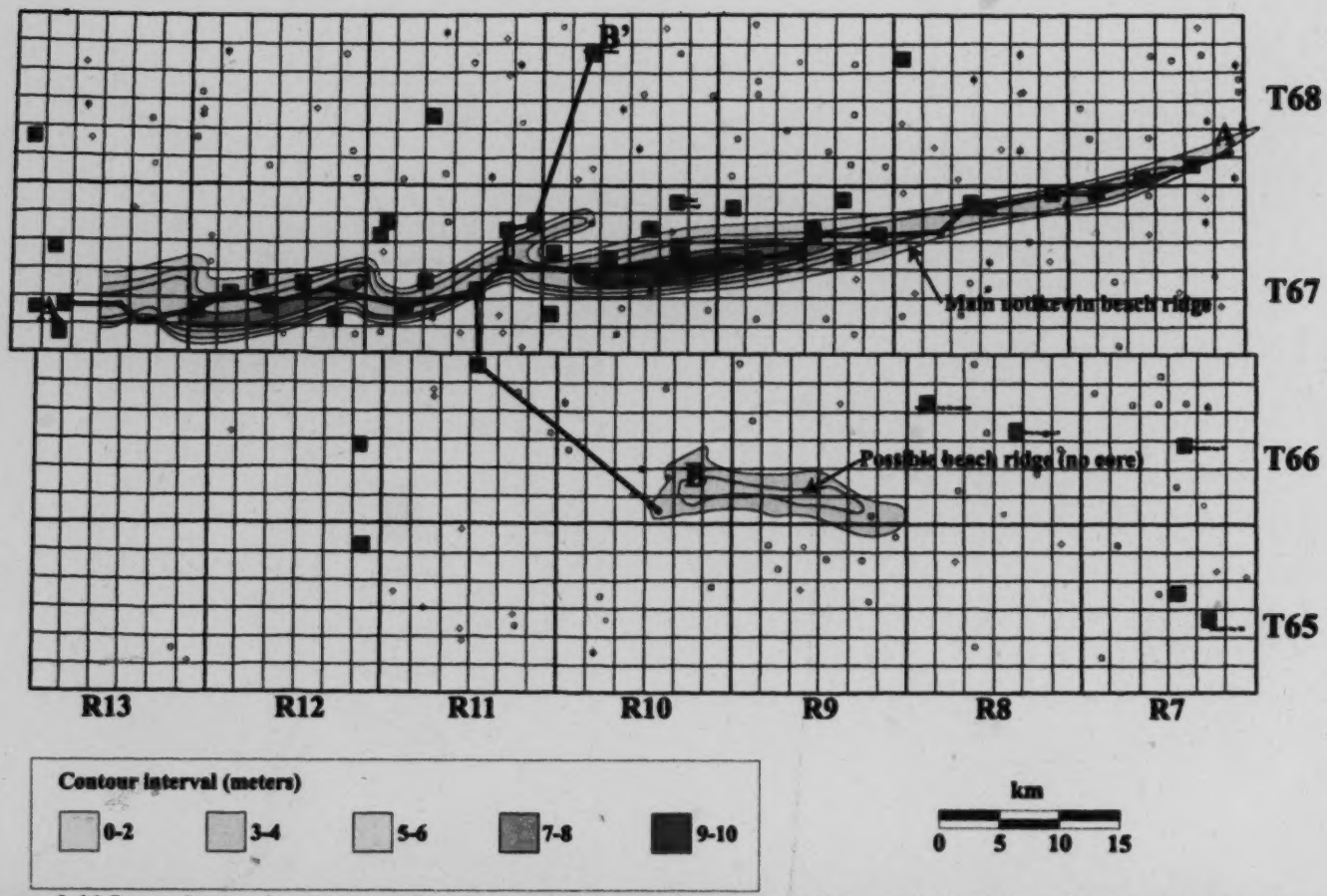



**Figure 2.11 Isopach map in meters of Beach (facies 3b) conglomerate (before erosion). The main succession trends east-west and thins to the east. No conglomerate is present in the middle Notikewin west of study area. A second beach trend is inferred from comparison with petrophysical well logs in township 67, ranges 9 and 10 west of the 6th meridian.**

settings . Burrows of *Skolithos* passively filled with material from an overlying layer were also noted, and indicate that some open burrow systems were maintained in the system. Although similar in appearance to a *Glossifungites* surface, there are marked differences between the two. The relatively coarse grained occurrences in the Notikewin lack the same scale of temporal connotation as more conventional *Glossifungites* surfaces. The coarse sand in the beachface is strongly compacted by the pounding action of the surf, and thus it is not necessary to bury sediments as deeply to develop a firm substrate. These surfaces likely represent only very short periods of non-deposition, or minor exhumation such as those caused by a storm scour.

*Macaronichnus segregatus* has frequently been noted in other deposits that have been interpreted as to represent a foreshore environment. These include the Horseshoe Canyon Formation (Saunders, 1989), the Cadotte Member (Saunders *et al.*, 1994), and the Bluesky Formation (Brekke and Pemberton, 1994).

Although shoreface sequences are fairly commonly described in the geological record, beach successions are not often recognized. Ancient examples in the Western Canada Sedimentary Basin include the Lower Gates (Leckie and Walker, 1982) and the equivalent Falher Members (Rouble and Walker 1997; Arnott 1994). Elsewhere, ancient beach deposits have been recognized in various localities along the Mediterranean sea (Massari and Parea, 1988, 1990). The primarily subaerial nature of these deposits result in low preservation potential of deposits. Even upper shoreface deposits are relatively rarely preserved, and are typically removed from the geological record during sea level rise and resultant wave ravinement.

Although beach deposits are not commonly preserved in the geological record, it has been noted that in strongly progradational sequences, there is a greater chance of preservation (Dickenson *et al.*, 1972). The recognition of these types of deposits depends on the ability to differentiate them from similar appearing deposits such as would be found in various fluvial environments. Bourgois and Leithold (1984) described a number

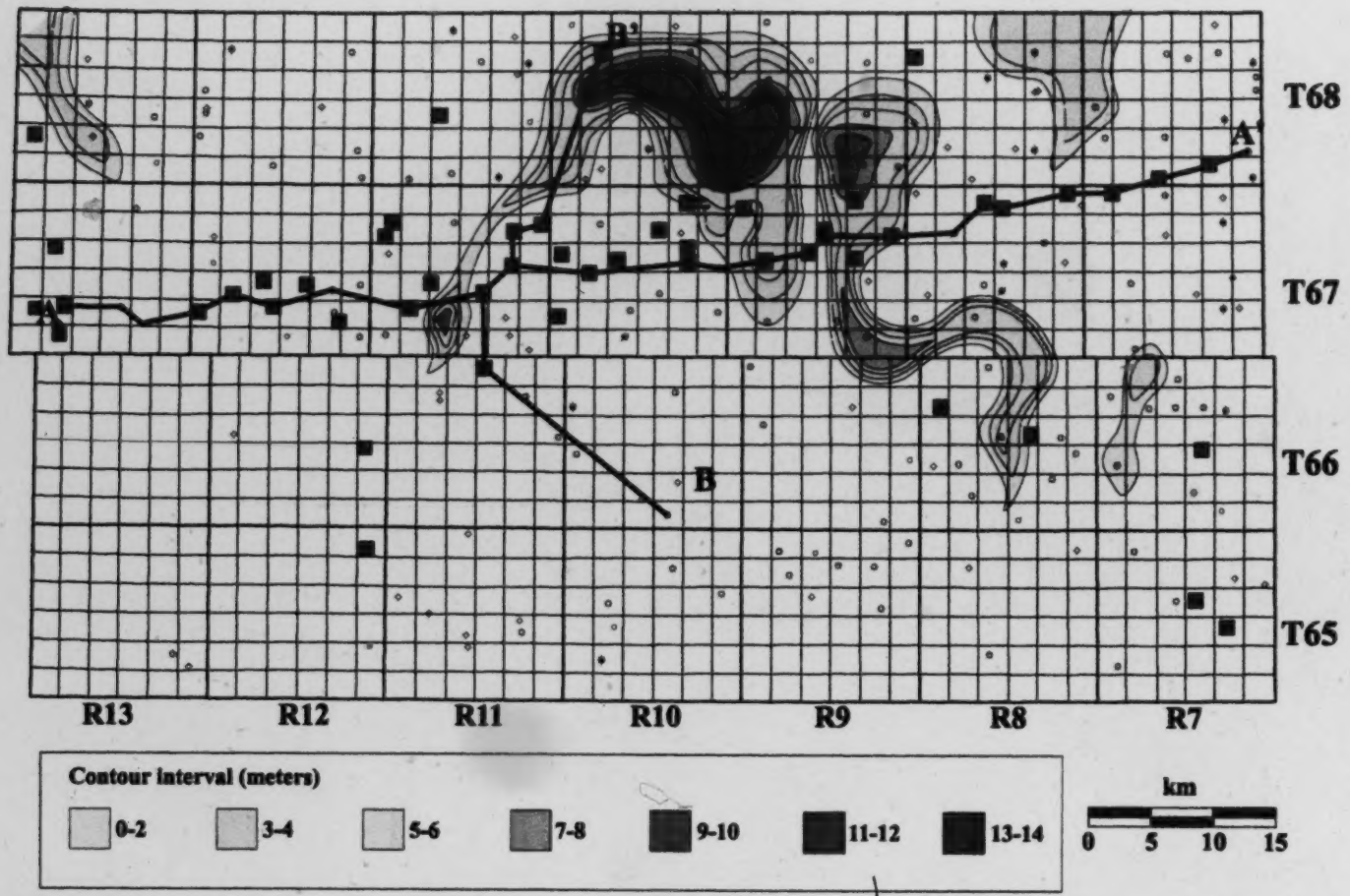



**Figure 2.12. Gross sand and conglomerate of the lower Notikewin Member. Overall these trends are consistant with an incised valley interpretation.**

of criteria that would allow the discrimination of conglomeratic beach deposits from other types of deposits. These include; good size and shape sorting, presence of imbricated, disc shaped pebbles and, the identification of the vertical succession of facies in which they are contained as a shoreface to beach environment. This facies possesses the greatest degree of sorting of all facies observed in this study, alluding to sorting by marine processes. Clasts displayed a high degree of rounding and were texturally very mature. Weak imbrication was rarely seen, however it is likely that given a larger exposure such as at outcrop scale, such features would be more evident. The strongest line of evidence is in the succession of facies that contains good evidence for upper shoreface deposits below the beach deposits and lagoonal to continental deposits overlying them. Furthermore, comparison with petrophysical well logs and subsequent mapping of the beach conglomerate (Figure 2.11) demonstrates the shore normal orientation of the deposits when compared with regional Notikewin shoreline trends (Figure 1.7)

The two occurrences of the facies at the base of the Notikewin are also thought to represet wave winnowed deposits in an intertidal environment. A similar deposit at the base of the Notikewin was described by Carmichael (1988) and Leckie and Walker (1982). These deposits were interpreted to represent transgressive estuary mouth shoal or tidal delta deposits formed in valleys created at the end of Falher deposition. Although there is no trace or body fossils to support a marine environment of deposition, the well-sorted nature and stratigraphic position of the conglomerates below marine Notikewin sediments of FA2 seem to attest to a transgressive marine origin of these deposits. Conglomerate deposits associated with fluvial systems are unlikely to display such a high degree of winnowing. Although core control in the lower Notikewin member is limited, correlation with petrophysical well logs and mapping of overall sand and conglomerate thickness allows a general delineation of valley trends (Figure 2.12). This map demonstrates an orientation perpendicular to shoreface deposits of the middle Notikewin, further supporting an estuarine valley fill interpretation.

**FACIES ASSOCIATION 4: Marginal marine restricted deposits.**

Facies Association 4 (FA4) consists of 2 facies; 4a (Carbonaceous shale with fine sand laminations) and facies 4b (ripple laminated to parallel laminated sand).

**Facies 4a: Bioturbated shale with fine sandstone**

Description:

*Sedimentological characteristics*: Facies G consists dominantly of shale, with minor sandstone and coal laminations and rare granule layers. It is present in at least 25 cores within the study area. Typically only a very thin interval is cored as it typically occurs immediately above the main reservoir unit (Facies association 3). The lower contact is sharp. Extensive rootlets may extend from the contact into the underlying units. Due to core control, the upper contact is seldom observed, but the facies may reach thickness in excess of 6 meters with an average thickness of approximately one meter.

In many cases, the succession fines upwards, but it is occasionally truncated by other coarser facies. Bedding is often difficult to observe in the shale layers, but when inter-laminated with fine sandstone, the bedding is observed to be primarily planar. Occasional lenticular to wavy bedding is also observed (Fig 2.13d). In successions with high amounts of bioturbation, the primary bedding may be reworked to such an extent that the sediment is completely homogenized and physical sedimentary structures are unrecognizable. Sediment deformation occurs locally and is manifested in small syn-sedimentary faulting and rare convolute bedding. Shrinkage cracks occur frequently in shale layers and are recognizable when in-filled with sand. Coal laminations consist of anthracite and are generally a few millimeters in thickness. Granules also rarely occur, typically in thin bands, interspersed within the shale.

Siderite is a common accessory that may occur in bands or nodules. Pyrite is rare

**Figure 2.13 Lagoon/bay deposits:**

**A)** 06-25-067-09w6, depth 2091.4m: Intensely bioturbated fine sandstone and shale with abundant *Helminthopsis* and occasional *Asterosoma* (As), *Cylindrichnus* (Cyl) and *Teichichnus* (Te).

**B)** 08-22-066-08w6, depth 2470.0m: Finely inter laminated sandstone and shale with microfaulting.

**C)** 11-14-065-07w6, depth 2493.0m: Moderately bioturbated sandstone and shale with *Planolites* (Pl), *Rosselia* (Ro), *Skolithos* (Sk), and *Teichichnus* (Te).

**D)** 15-15-066-07w6, depth 2296.5m: Interlaminated to lenticular bedded fine sandstone and shale with low degree of burrowing consisting of diminutive *Planolites* (Pl) and *Skolithos* (Sk).

A
cm
I.R.G.
Technology Research Group

B
cm
I.R.G.
Technology Research Group

C
cm
I.R.G.

D
I.R.G.

and may occur in a number of forms. It is observed as isolated nodules, and in clusters or bands. Rarely, pyritized fossil fragments (bivalves) are present. Bivalve shell fragments occur either singularly or in a thin concentrated layer.

*Ichnological characteristics*: Bioturbation is generally sparse but may be locally abundant. Typical diversity in these areas is low and typically consists of monospecific assemblages. Traces are more readily discernable in the sandy layers, suggesting that there is much greater burrowing activity in the shaley units than can be recognized. Trace fossils observed include *Asterosoma* (rare), *Cylindrichnus* (rare), *Helminthopsis* (rare) diminuitive *Planolites* (common), *Chondrites* (rare), *Palaeophycus* (moderate), *Rosselia* (rare), *Teichichnus* (very rare), *Skolithos* (very rare), *Thalassinoides* (moderate) and root traces (rare).

Interpretation

Facies 4a displays characteristics that are consistent with a quiescent environment with little influence of current energy. Physical sedimentary structures indicate that the primary current shaping these sediments was likely tidal in origin. Lenticular and wavy bedding are often intimately associated with tidally influenced deposits. Deformation structures such as syn-sedimentary faulting and convolute bedding are often indicative of high sedimentation rates, but may also occur in sediments adjacent to channels, where undermining of banks results in the collapse of strata. Close association of this facies with deposits interpreted as tidal channels (facies 4b) support this interpretation. Shrinkage cracks are interpreted as syneresis cracks caused by fluctuations in salinity.

Coarse-grained deposits in quiescent environments may be deposited in a number of different manners. Generally however, this would result from an increase in current energy within the environment. Since there is little evidence in this facies of high energy current generated sedimentary structures, it is thought that the granules may represent

material washed over from the beach-face during periods of high wave energy. Therefore, they should not be considered to represent any temporally significant deposit such as a transgressive lag.

Trace fossil occurrence in facies 4a is characteristic of brackish water deposits. Such characteristics have been summarized by Pemberton and Wightman (1992) and include; 1) a reduction in overall species numbers when compared with marine and fresh-water deposits. 2) low species diversity with high individual density, and 3) Diminished size of both burrows and tracemakers;

In apparent contradiction with these characteristics, deposits of facies 4a contained a relatively high number of species when compared with fully marine shoreface to offshore deposits of FA1 and FA2. Notikewin shoreface sediments are interpreted to be of extremely high energy levels and consist mostly of storm generated deposits. Consequently, the full range of species has not been preserved. In such a situation, back-barrier environments may provide a protection from the extreme wave energy levels, which have influenced shoreface deposition. The fairweather back-barrier assemblage is preserved giving the illusion of higher species diversity. Therefore, the brackish water model is still applicable.

Other characteristics of brackish water such as localized individual density was frequently observed in sediments of facies 4a (Figure 2.13A). In addition, the traces were found to be of a relatively diminished size, indicating that the tracemakers were also of a smaller stature. This type of adaptive behavior is attributed to an attempt to reduce the surface area of the organism to better adjust to salinity fluctuations and withstand the forces of osmosis (Milne, 1940).

**Facies 4b: Ripple laminated to parallel laminated bioturbated sandstone**

Description

*Sedimentological characteristics*: Facies 4b consists of fine to very fine grained sandstone which often grades upwards into the bioturbated siltstone and shale of facies 4a. It may also erosionally overly facies 4a. This facies ranges in thickness from 10 centimeters to 9 meters. Internal discontinuities in the form of reactivation surfaces are common.

A granule lag deposit, which ranges in thickness from 5 to 50 centimeters, often marks the base of this facies. The conglomerate is poorly sorted and is often interspersed with, or supported by fine sandstone. Clasts are sub-angular to sub-rounded. Occasional trough cross bedding and planar lamination can be seen in the upper portions of the conglomerate.

The sand is often trough cross-laminated at the base, and grades upwards into planar and ripple cross-laminated beds. Rare oscillation ripples also occur towards the top of the section. Other sedimentary structures observed include micro-faulting and soft sediment deformation. Roots and coal laminations are rarely present. Thin shale laminations occur as drapes or couplets, especially in the upper portions of a given succession. The roots often appear just below the upper contact with facies 5b, with which they are likely genetically related. Siderite occurs rarely as parallel bands

*Ichnological characteristics*: The base of the facies is often demarcated by a *Glossifungites* surface, with sand or conglomerate of the overlying sediment being piped down open burrow systems into the dominantly muddy strata below (Figure 2.15 A-C). This surface is associated with burrows of *Diplocraterion, Skolithos* and *Thalassinoides.*

Bioturbation is sporadic but may be locally common. Burrows observed were *Conichnus* (rare), *Cylindrichnus* (moderate), *Diplocraterion* (moderate), *Macaronichnus segregatis* (moderate), *Palaeophycus* (moderate), *Planolites* (common), *Skolithos* (rare),

**Figure 2.14 Tidal channel deposits**

**A)** 11-22-065-07w6, depth 2529.6m: Very fine grained tidal channel deposits, moderately bioturbated with *Macaronichnus segregatus* (Ma) and rarer *Planolites* (Pl). This photo represents an atypical occurrence of *M. segregatus*, as generally it is found exclusive of other traces and tends to display more densely packed burrows. There is also a much greater vertical component in the burrows when compared with occurrences in the upper shoreface.

**B)** 11-14-065-07w6, depth 2490.6m: planar laminated sandstone with double mud drapes (md) grading into ripple cross-laminated fine sand in the upper portion of a channel sequence.

**C)** 11-14-065-07w6, depth 2492.0m: Planar laminated to massive fine grained sandstone with robust *Teichichnus* (Te).

**D)** 11-14-065-07w6, depth 2492.6m: *Cylinidrichnus* (Cyl) in parallel laminated fine sandstone with double mud drapes (md).

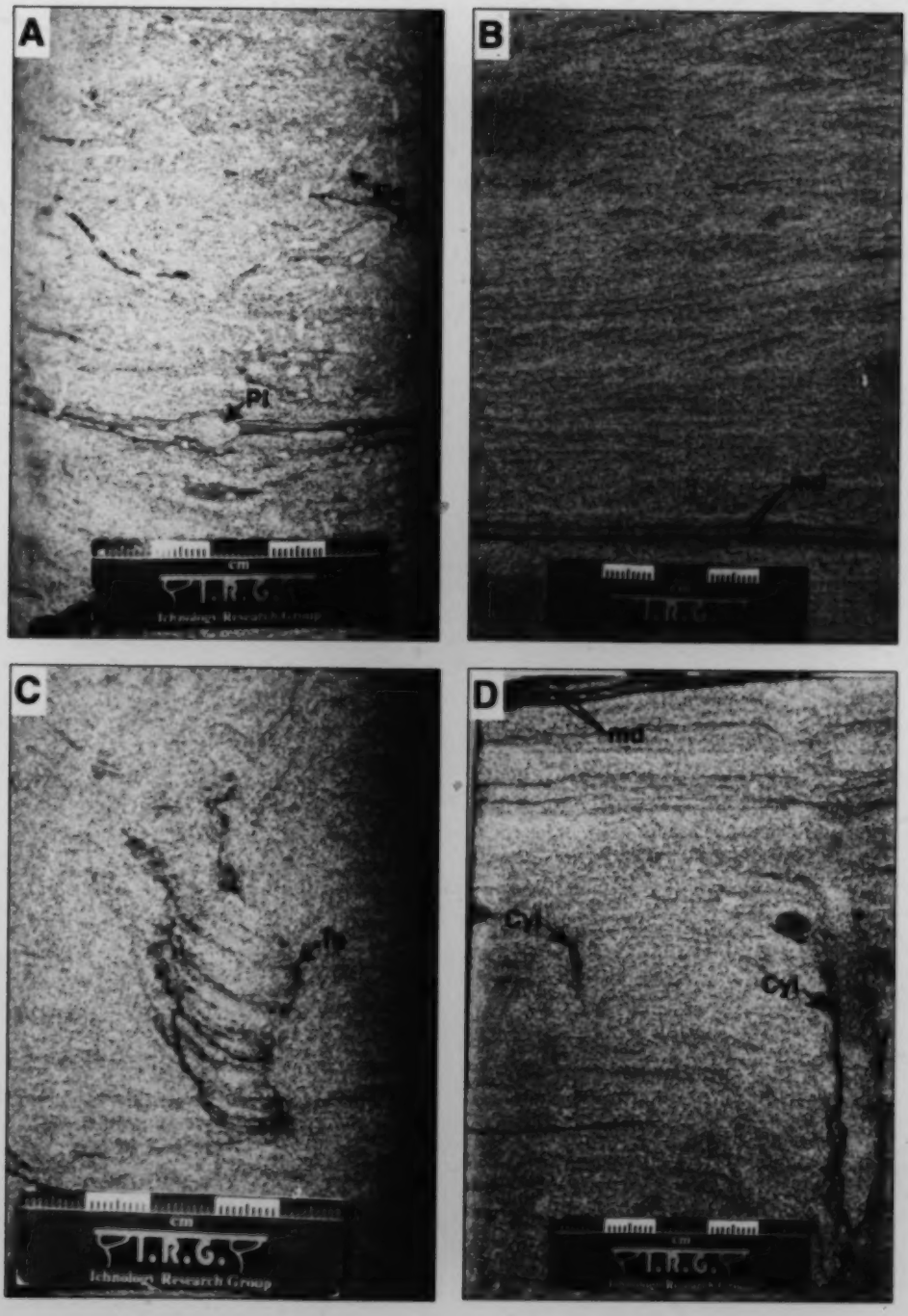

A
Pl
B
C
D
md
cyl
cyl

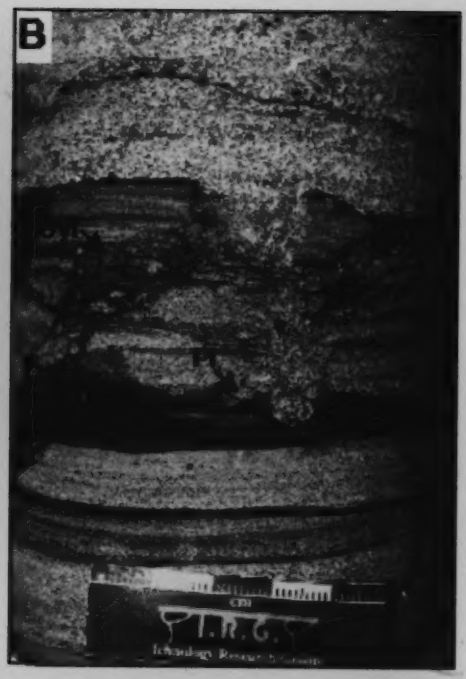
**Figure 2.15 Trace fossil demarcated tidal channel surfaces**

**A)** 11-22-065-07w6, depth 2520.4m: Trough cross-laminated sandstone representing the base of a channel sequence overlie parallel laminated finer sandstone of waning stage flow. The channel re-activation surface is demarcated with robust *Diplocraterion* (Di). This surface does not have the temporal significance of a *Glossifungites* surface, as sand lithifies much more quickly then mud.

**B)** 11-22-065-07w6, depth 2527.4m: Trough cross-laminated basal channel sand overlying lagoonal sediments of facies 5b. This surface is demarcated with a *Glossifungites* surface with *Thalassinoides* (Th) and *Cylindrichnus* (Cyl) piping channel sand into the underlying lagoonal deposits. Some significant burial and re-exhumation must have occurred for the underlying fine deposits to become firm enough to allow the burrows to stay open while coarse channel sands was deposited into them. *Planolites* (Pl) is also present.

**C)** 11-22-065-07w6, depth 2526.0m: Trough cross-laminated channel sand overlying parallel laminated upper-channel deposits with *Thalassinoides* (Th). This surface resembles a *Glossifungites* demarcated discontinuity however it does not have the same temporal significance as no true firm ground was developed.

A


B

*Teichichnus* (rare) and *Thalassinoides* (rare).

Unlike occurrences in other facies within the study area, *Macaronichnus segregatus* was observed in association with other traces. It was also not as prolific as in upper shoreface deposits and was observed to display a large component of vertical movement.

Interpretation:

Facies 4b is interpreted to represent deposition in a tidal channel or tidal influencd bayhead delta environment. The fining upward sequence and grading of sedimentary structures from trough cross-bedding to planar lamination are typical of waning current energy conditions, associated with migrating channel deposits. Deposits displaying sediment deformation and faulting are interpreted to represent deposition near the bank edge. Channel edge deposits would be prone to faulting and collapse due to undermining of bank edges during channel migration.

The presence of a relatively diverse amount of bioturbation indicates a marine influence on the system. Tidal influence is also clearly seen by several features. The drapes and couplets are interpreted as tidal in origin, and are deposited during alternating flow conditions associated with tidal cycles. The presence of oscillation ripples is indicative of bi-directional current flow. Re-activation surfaces are also commonly associated with, or diagnostic of tidal environments (Nio and Yang, 1991).

The relatively high ichnologic diversity of these deposits when compared with the seaward deposits in the Notikewin suggests that the back-barrier environment presented less stress to the organisms. The high-energy conditions thought to be the dominant stress in offshore to foreshore deposits are clearly not as effective in the back-barrier. This may imply that barrier breaching by waves was a relatively rare event, even during winter storms. However, when compared with normal marine conditions in typical low energy deposits, bio-diversity and abundance was low in this facies. Low salinity was likely the dominant stress in these deposits.

Tracemakers of *Macaronichnus segregatus* such as the polychaete *Euzonas* sp. have been thought to have resistance to fluctuations in oxygenation (Ruby and Fox, 1976). In foreshore and upper shoreface environments, this resistance could allow them to proliferate in what would otherwise be a harsh environment. Typically *Macaronichnus* tracemakers dwell infaunally and may survive several meters below the sediment water interface. Because of their ability to exploit this generally inhospitable environment, they occur in dense monospecific populations. It is very rare to see them associated with other traces. In the Notikewin, they are seen to exist exclusive of all other traces in the uppermost upper shoreface. The traces found in tidal channel deposits display characteristics that are in sharp contrast with the upper shoreface examples. Their association with other traces and less dense population indicate that they did not have the competitive advantage that they often maintain in upper shoreface and foreshore environments. This occurrence of *Macaronichnus* may represent opportunistic or pioneering behavior of tracemakers transported from the foreshore and uppershoreface environments in which they are generally more successful.

## FACIES ASSOCIATION 5: Continental fluvial to deltaic

Facies Association 5 is divided into 4 facies; 5a, fining upwards sand and conglomerate and 5b; non-bioturbated silt and shale and 5c; coal.

### Facies 5a: sparsely to non-bioturbated silt, shale and coal

Description

Facies 5a consists dominantly of silty shale with coal interlaminations and interbeds. It gradationally overlies marginal marine deposits of Facies Association 4. The upper contact is rarely cored however facies 5b is occasionally unconformably overlain be facies 5a.

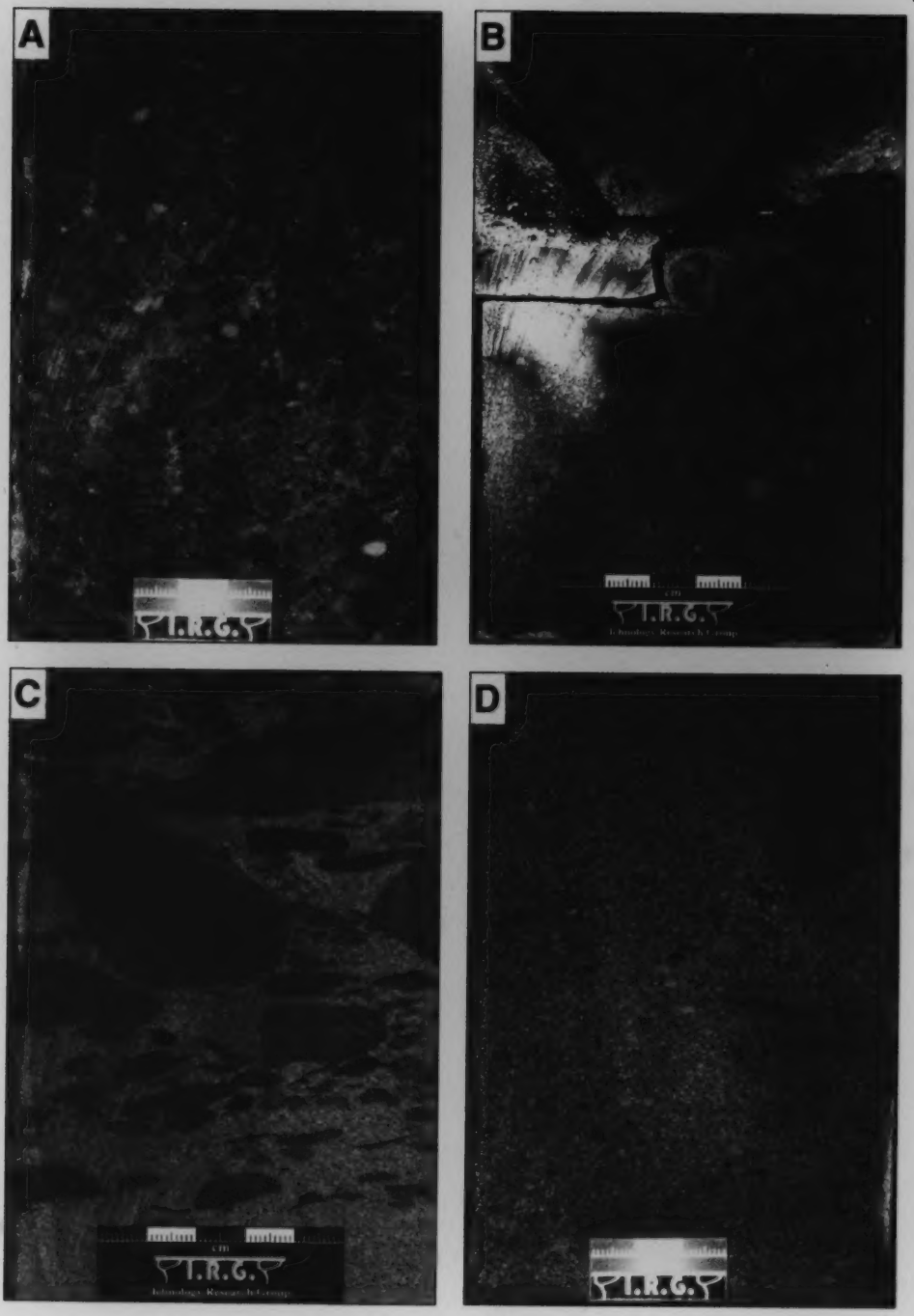
**Figure 2.16 Channel deposits**

**A)** 10-08-067-13w6, depth 2691.2m: Basal channel deposits represented by matrix to clast supported bimodal conglomerate.

**B)** 10-08-067-13w6, depth 2688.2m: Large mud rip-up clasts in channel sands. The large size and angularity of the clasts indicates a short transport distance. The clasts appear similar in lithology to some lagoonal deposits.

**C)** 10-08-067-13w6 depth 2681.4m: Angular to rounded mud rip-up clasts.

**D)** 10-08-067-13w6 depth 2688.6 m: Fine grained channel sands with abundant interspersed pebbles reflecting poor sorting and maturity of clasts.


A
B
C
D
I.R.G.

*Sedimentological characteristics*: Laminations are predominantly planar with common soft sediment deformation in the form of micro faulting and convolute bedding. The coal occurs as thin laminations generally only a few millimeters thick. In some occurrences, syneresis cracks are observable.

*Ichnological characteristics*: Overall, this sequence displays very little no bioturbation. Some rare features exist which could represent diminutive *Planolites* or *Skolithos* burrows. These typically occur in the lower silty portions of the beds. Root traces are the only common biologically generated element.

Interpretation:

These deposits are interpreted to represent non-marine deposition in a quiescent environment. This could include a variety of environments including deposition within ponds or lakes, and fill in abandoned channel systems.

**Facies 5b: Planar laminated to massive sandstone**

Description:

This facies occurs in 4 of the cores examined in this study. This very fine to fine grained sandstone is relatively poorly sorted when compared with coarser deposits recognized in this study. Due to the concentration of cores in the coarser reservoir quality facies, there is much less core data available for the interpretation of this interval. The sandstone was generally massive to planar-bedded, though some small scale trough cross bedding was rarely observed. The sand was much more poorly sorted than within other fine sandstone facies, and included more mud and carbonaceous debris. Mud and coal rip-ups are common, and in places these reached diameters of up to 10 cm (Figure 2.16B). Often rip-ups are very angular, indicating a short transport distance. Some of the clasts

appeared derived from a similar lithology as in lagoonal deposits of facies 5c.

This facies ranges in thickness from 2.4 meters to greater then 15 meters in thickness. The thicker sequences are at a stratigraphic level equivalent to the shoreface and beach deposits of FA2 to FA4. Thinner successions occurred above these deposits. There was no evidence of biogenic activity in any occurrence of this facies except for some root casts,

Interpretation:

Facies 5b is interpreted to represent fluvial channel or dune deposits. When compared with shoreface sands, fluvial deposits generally display poorer sorting and textural maturity (Bourgois and Leithold, 1984). When correlated with well logs, this facies was found to be limited in lateral extent. In addition, the lack of biogenic activity is consistent with an interpretation as a non-marine succession. Massive sandstones may also represent deposits in a dune environment.

Thicker channel deposits are found in the extreme western portion of the study area. Correlation with well logs indicated that this was a thick channel succession in excess of 30 meters in thickness, and with a base at about the same stratigraphic level of the shoreface deposits. This channel succession may have been deposited contemporaneously with laterally equivalent shoreface deposits or it may have incised into these shoreface deposits on subsequent low-stand of sea level. An interpreted map of gross sand for this facies was constructed and used to predict palaeo-channel locations (Figure 2.17). This map is a composite for channel sands throughout the Notikewin interval. It demonstrates that one of the major channels in the southwest portion of the study area follows the axis of a syncline. The position of this channel coincides with the westerly occurrence of conglomerate in the middle Notikewin unit. It is interpreted that this channel may have provided source material for the Notikewin shoreline.

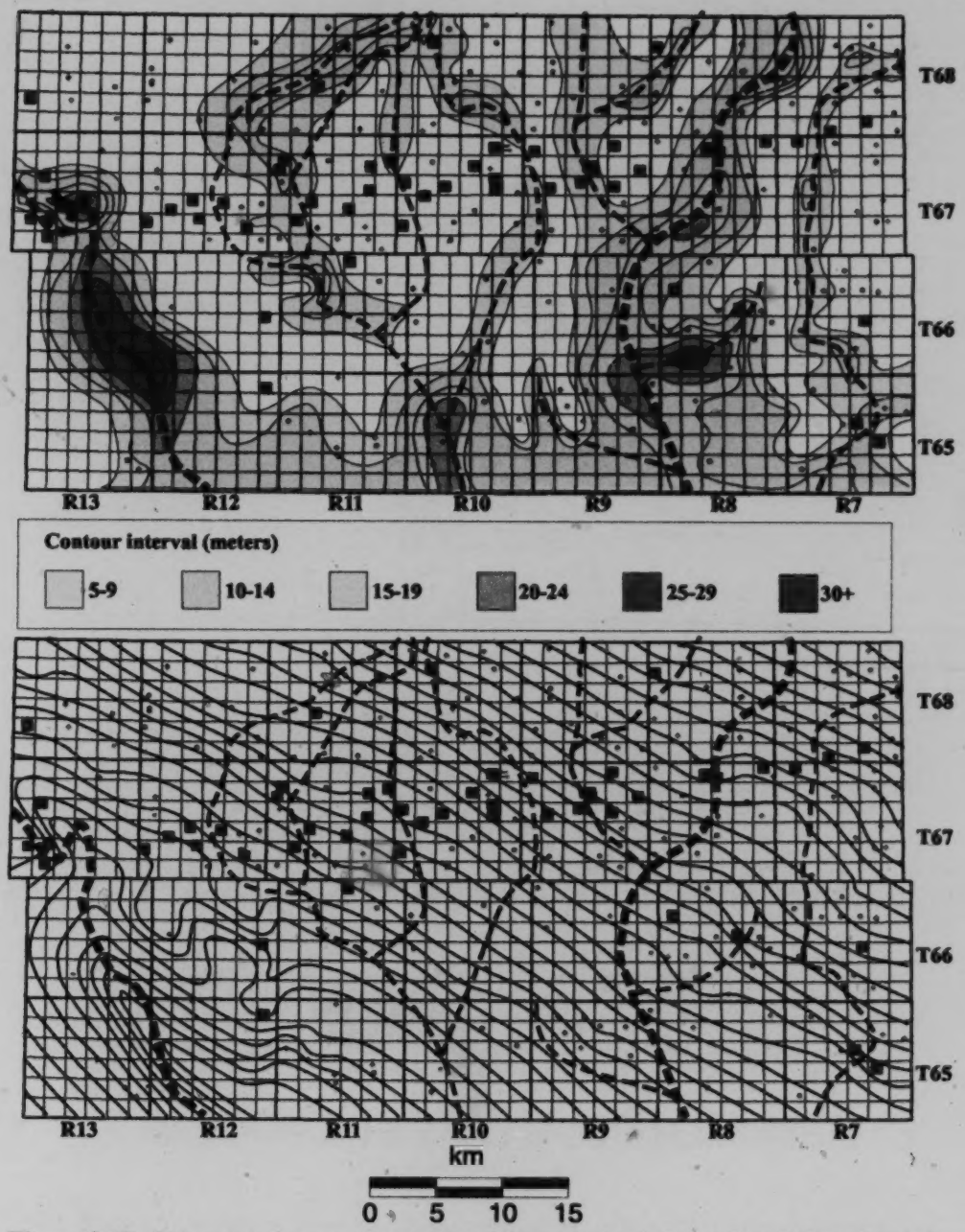



**Figure 2.17. Interpreted gross channel sand isopach (top), is used to define channel trends (dashed lines). When compared with structure (bottom), a strong relation between one of the major channels (purple dashed line) and a structural low is seen. See figure 1.3 for structural contour values and interpreted position of syncline.**

**Facies 5c: Polymodal angular conglomerate**

Description:

The polymodal conglomerate was rarely observed. It occurs in 2 wells, in one of which it exists only as a thin lag. Polymodal conglomerates of this facies are differentiated from other conglomerates in the study by the relative textural and lithologic immaturity of the clasts. Clast types included mud and coal rip ups, and poorly rounded chert and quartz. The matrix ranged from a fine to very fine-grained sand. This facies ranges in thickness from a few centimeters up to 3.2 meters. There were no biogenic structures observed.

Interpretation

The deposits of facies 5c represent the basal portions of channel successions described in facies 5b. Texturally immature material is likely sourced from adjacent coastal deposits and may represent bank collapse. Chert and Quartz pebbles are similar in lithology to those found in FA3 (uppershoreface and beach deposits). The largest of these channel deposits occurs at the western limit of the occurrence of the conglomerate in FA3 in wellbore 10-08-067-13W6. These channels likely represent point sources of coarse material to the shoreface.

**Facies 5d: Coal**

Description:

*Sedimentological characteristics*: Several sequences of coal occur within sediments of the Notikewin. The coal may occur in several different depositional sequences of the Notikewin, and is found at the base of the member as clasts mixed with sand or conglomerate deposits. More extensive deposits are found interstratified with facies association 4 (lagoon and bay deposits). The most extensive coals are found in the upper

portions of the Notikewin overlying facies association 3.

Coal is predominantly high rank anthracite. Because of the high coal rank, the coal is very uncohesive and typical core recovery consists of rubble. Consequently, it was not possible to accurately measure the maximum thickness of the seams, except for by extrapolation from geophysical well logs. Maximum thickness in Notikewin coals is thought to be slightly greater than 1 meter. When bedding is preserved, the coals exist as thin laminae in silt and shale sequences.

*Ichnologic characteristics*: Occasional root casts occur within the coal beds. No other biogenic activity is observed.

Interpretation:

Facies 5c is interpreted to have been deposited in a backshore lagoon or marsh environment. Coal is typically formed in non-marine environments with low deposition rates and relatively high organic content. (Reading & Collinson, 1996)

# CHAPTER3:

## ENVIRONMENTS OF DEPOSITION AND STRATIGRAPHY

### Barrier Formation:

An understanding of the role of sea level changes and relative position of the coastline is imperative for any discussion involving barrier formation. Transgression is defined as a landward translation of the shoreline. Regression is defined as a basinward translation of the shoreline. Neither term has any direct implication for sea level. Changes in sediment supply or subsidence rates may result in either transgression or regression irrespective of sea level change. Transgressive and regressive successions may be seen to occur within the same depositional sequence in closely adjacent areas. For example, as delta lobes are abandoned, they subside and are susceptible to transgressive reworking, coeval with formation of a new progradational delta lobe. As such, the analysis of a depositional sequence within a single core may not provide a complete understanding of sea level change. A large survey of the entire coastal area must be analyzed before any conclusion may be reached.

There has been much debate regarding the formation of barrier island systems. Three commonly cited models for barrier formation are: 1) Longshore spit growth across an embayment, 2) emergence of submarine bars, and 3) by flooding of coastal lowlands behind former dune ridges or beaches (Cooper,1994; Reinson, 1984). These mechanisms of barrier formation are effective in either stillstand or transgressive settings. However, during relative sea level fall, the backbarrier portion quickly fills in and the advancing shoreline takes the form of a strand plain (Roy *et al.*, 1994; Reinson,1984). Galveston Island is the most extensively studied modern progradational barrier island, however the lagoon in Galveston Island was formed during an overall transgression of the shoreline (Morton, 1979). Currently, global rises in relative sea level, allow the maintenance of a lagoon.

More recently, the "forced regression model" has been used to explain many of the stratigraphic sequences in the Western Canada Sedimentary Basin (Plint, 1988; Posmentier *et al.*, 1992). A forced regression is defined as a basinward movement of the shoreline caused by a fall in relative sea-level, and independent of sediment supply (Posamentier *et al.*, 1992). This type of shoreline progradation results in the development of a sequence boundary known as a regressive surface of erosion (Posamentier and Allen, 1999). Typically this boundary is recognized by a displacement of facies with proximal shoreline deposits overlying distal deposits with minimal development of intervening gradational sediments. Further basinward, this contact becomes more gradational, until accommodation space allows for the development of the complete sequence. The resultant deposit takes the form of a wide strand plain without significant estuaries or lagoons (Roy *et al.*, 1994).

Recognition of this type of sequence boundary may be problematic in high energy sequences where sharp facies boundaries are frequently a result of storm deposition rather than sea level change. Criteria used for the recognition of forced regressive systems are the presence of gutter casts, mud rip-up clasts, and the sudden shift in facies above and below the contact (Posamentier and Allen, 1999). Other useful criteria is a well defined and mapeable *Glossifungites* surface may be developed (MacEachern, 1994).

Unfortunately, some of these features may not be as likely to be preserved in high energy shoreface deposits. In high energy storm dominated systems, sand may be deposited far from shore into the offshore zone. In such a system it would not be likely to preserve mud rip-up clasts. Also, gutter casts may be difficult to recognize in core due to the small scale of observation. In addition, there is often a lack of bioturbation in these high energy sequences, so trace fossil demarcated surfaces may not be developed. Without these pieces of evidence, all that is left to identify these sequences are incidents of displaced facies across the erosional boundary.

It is unlikely that any sequences with extensively preserved lagoon deposits could

represent deposition during falling sea level, although such interpretations have been made in the past (Caddell 1999, Plint 1988, Armitage 2002). The Notikewin Member has been previously interpreted as prograding as a regressive barrier island system by as much as 150 kilometers in Northeast British Columbia (Leckie, 1985), and 38 kilometers in Northwest Alberta (Smith, 1984). Because extensive lagoonal sediments are preserved in the Notikewin, it is unlikely that the sediments could represent a regression, as the lagoon would have quickly been filled in and the shoreline would take the form of a strandplain.

Similar coarse grained deposits in the Spirit River Formation have been interpreted to represent falling sea level deposits (Caddel 1999, Armitage 2002). In these studies of the Falher 'C' member, the sharp boundary between lower shoreface sands and upper shoreface to beach conglomerate deposits is interpreted to represent a RSE and therefore a forced regressive emplaced shoreface. Although the sequence of facies seen in these studies is similar to those seen in the Notikewin Member in the Wapiti area, a different interpretation of the depositional events is favored.

While the proximal lowershoreface deposits (facies 2a,2b) in the Notikewin member, are generally fine grained, bands of pebbles or isolated pebbles are frequently observed. These pebbles are similar in rounding and size to many of the clasts found within the upper shoreface and beach deposits. The presence of these pebbles in more distal deposits indicates that conglomerate was being introduced into the depositional system contemporaneously with lower shoreface deposits. This provides evidence that the deposits above and below the contact are genetically related.

In addition, extensive lagoonal deposits are seen to occur above and behind the Notikewin Member (Facies Association 4). In sequences deposited during sea level fall, the water table is lowered and lagoon deposits are not likely to form. These deposits are characteristic of transgressive coastlines. While it is possible that limited lagoon deposits could be formed in ephemeral ponding behind the beach deposits, it is likely

that the presence of extensive deposits above beach sediments is evidence for sea level rise rather than sea level fall.

The surface between the lower and upper shoreface deposits of the Notikewin (Facies 2a,b and facies 3a respectively), has been discussed in detail in chapter 2.

Although there is a sharp grain size contrast across the contact, the surface has been shown to be a result of normal shoreface depositional processes. As these types of deposits may occur laterally to each other, Walther's Law has not been violated and it would not be parsimonious to invoke a sequence boundary to explain the succession of facies. It is therefore interpreted that within similar sequences in the Notikewin, there was no rapid drop in sea level, and thus a forced regressive shoreface emplacement is not favored.

**Stratigraphic surfaces:**

Past studies in the Wapiti area have only briefly described the stratigraphic architecture of the Notikewin Member. Cant (1984) described the Notikewin as a single coarsening upward sequence that splits into 2 sequences basin-ward due to a minor transgression. Carmichael (1988) elaborated on Notikewin stratigraphy in the Northeastern British Columbia region, describing transgressive estuarine deposits at the base of the unit capped by upper Notikewin regressive shoreline deposits. Analysis of the facies distributions and key surfaces present in the study area allows the development of a more detailed stratigraphic model. An allostratigraphic approach for correlation using bounding continuities similar to those described by Bhattacharya (1993), is used in this study.

In the Notikewin there are several breaks in sedimentation observed in core that could be traced over varying distances. Analysis of the facies above and below these breaks indicates that they frequently separate fundamentally different depositional

environments. There are two major types of breaks in sedimentation that are recognized in the Notikewin Member. These are surfaces that represent an abrupt deepening of relative sea level, and surfaces that represent a relative drop in sea level.

Transgression may occur with or without significant erosion. When erosion does occur, the surface that results is called a transgressive surface of erosion (TSE) or a ravinement surface (Bhattacharya, 1993). Surfaces without significant erosion are termed marine flooding surfaces.

Surfaces that represent relative drops in sea level have been referred to in the literature as sequence boundaries (Van Wagoner et al., 1990). The surface produced by this process has also been referred to as a regressive surface of erosion (RSE) (Bhattacharya and Walker, 1991), and as a lowstand surface of erosion Weimer (1988).

Transgressive Surfaces in the Notikewin member:

Most of the sediments representing the Notikewin member have been influenced by high wave energies. As is common in the depositional record, many low energy deposits are often under-represented in the depositional record. While shoreface sequences are generally noted to be approximately 10m (Clifton 2000), there are several intervals of unbroken sedimentation within the Notikewin that are much greater then this. This is a result of the erosional amalgamation of several sequences into one apparent coarsening upward interval. By analysis of all of the available cores, it is seen that the Notikewin member represents several distinct sequences.

As previously stated, a flooding surface is recognized where there is an abrupt deepening in depositional environments. The most recognizable manifestation of this in the Notikewin is when marine sediments overly continental deposits.

Figure 2.1 is a representative depositional dip section for the Notikewin Member. A transgressive surface of erosion is recognized at the base of the Notikewin. It is recognized in several core including 10-29-068-10w6 that is incorperated into cross

section B-B' (Figure 3.1). A marine flooding surface separates transgressive deposits in the basal Notikewin from overlying regressive sequences. This is identified as a maximum flooding surface (MxFs) in sequence stratigraphic terminology. These lower Notikewin transgressive deposits are collectively named the Notikewin T1. A marine flooding surface separates the middle Notikewin into 2 regressive shoreline units. These are termed the Notikewin R1 and the Notikewin R2.

Regressive surfaces in the Notikewin:

Surfaces across which there was a drop in relative sea level were also recognized in this study. These are recognizable where continental deposits overly marine or shoreface deposits. This type of boundary separates the Notikewin R2 shoreline unit from overlying continental deposits. In sequence stratigraphic terminology this surface would be described as a regressive surface of erosion (RSE) (Posamentier and Allen 1999). Regardless of the terminology, it represents a dramatic shift in the position of the shoreline.

**Notikewin depositional sequences**

Notikewin T1:

The Notikewin T1 has rather poor core control, which prevents detailed studies of the unit. Lower shoreface deposits (Facies 1a) are recognized in 10-29-068-10w6. Facies 3b (foreshore) is recognized in 11-35-067-09w6. Though the data control was limited, mapping of this unit indicated that it was confined to a limited lateral extent and trended approximately North to South (Figure 2.12).

In Northeastern British Columbia, Leckie (1985) noted that the transgressive sequence was generally represented as a lag deposit with minimal amounts of shoreface sediment deposited, indicating relatively rapid transgression. In studies of outcrop along

OVER SIZED PAGE REMOVED

Mt. Frame, and the Babcock area Carmichael (1988) noted that transgressive bodies could be as thick as 40 meters and represented an estuarine environment with marine working of sediments.

Given that similar deposits have been recognized at the base of the equivalent Gates Formation (Leckie and Walker 1982, Carmichael 1988), an interpretation of the Notikewin T1 as a transgressive estuarine complex is considered the most likely interpretation. Accommodation for these deposits was likely generated during Falher A time due to fluvial incision. The general palaeogeography of this unit is summarized in Figure 3.2.

Notikewin R1:

Similar to the Notikewin T1, this unit was rather poorly cored. Elements of FA2 were most commonly recognized in this sequence. Facies 1b was recognized in the Notikewin R1 in borehole 16-16-068-11w6 indicating that deltaic processes were important in the deposition of this unit. FA1 was also recognized in this unit. Upper shoreface elements of facies 3a were recognized in 2 of the core (13-13-066-12w6 and 07-27-067-10w6). In the 07-27 core, most of the unit is represented by facies association 2 (lower shoreface), indicating that this unit likely prograded on the order of 13 to15 kilometers. By comparison with well logs, it is thought likely that beach deposits exist in the southern portion of the study area (Figure 3.1). Overall, the facies found in this unit are consistent with a progradational wave domainated strandplain to deltaic unit, summarized in Figure 3.3.

Notikewin R2:

This unit represented the most thoroughly sampled interval in the study area. Most of the cores in the study area were taken in this unit, due to the large volumes of hydrocarbons contained within beach deposits of this unit. Upper shoreface and beach

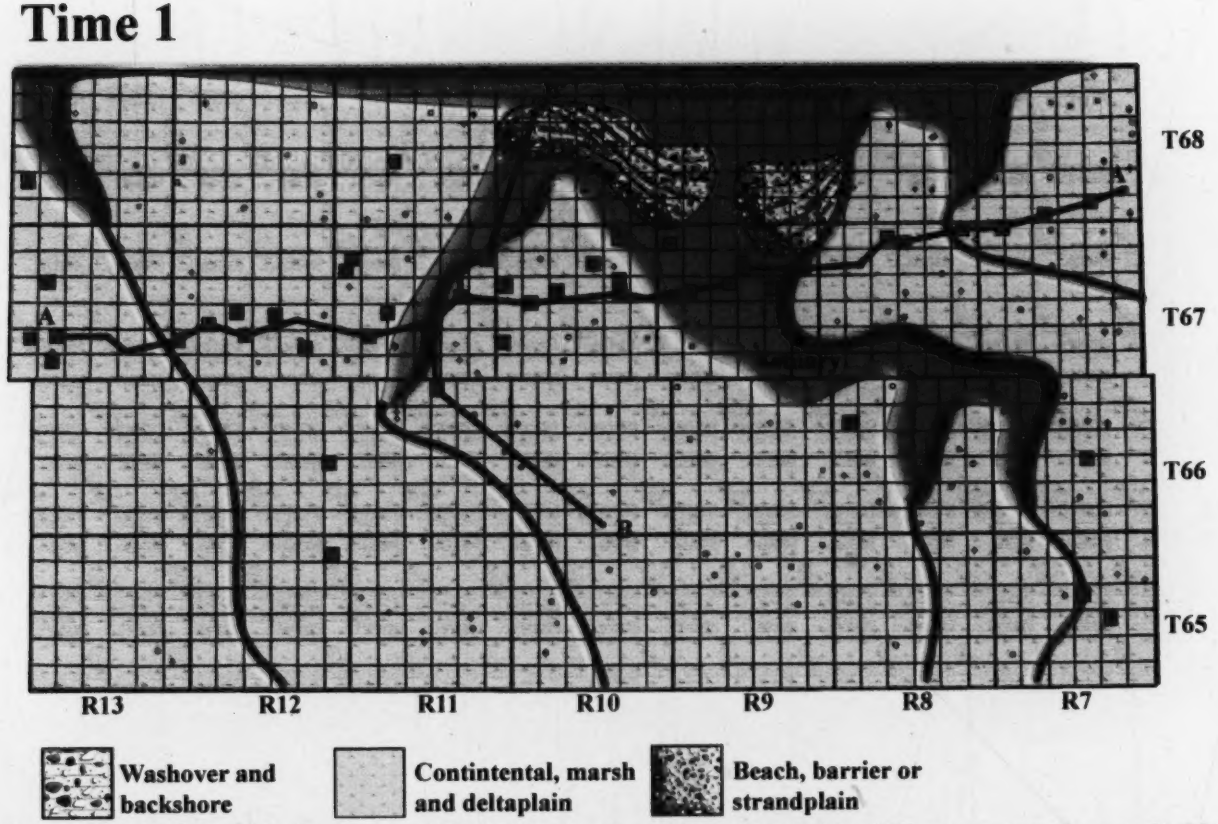



**Figure 3.2. Palaeogeography during the deposition of T1. Following deposition of the Fahler "A" , a transgression resulted in the development of wave dominated estuarine systems in the lower portions of the Notikewin Member. Limited core control was available for reconstruction of this unit.**

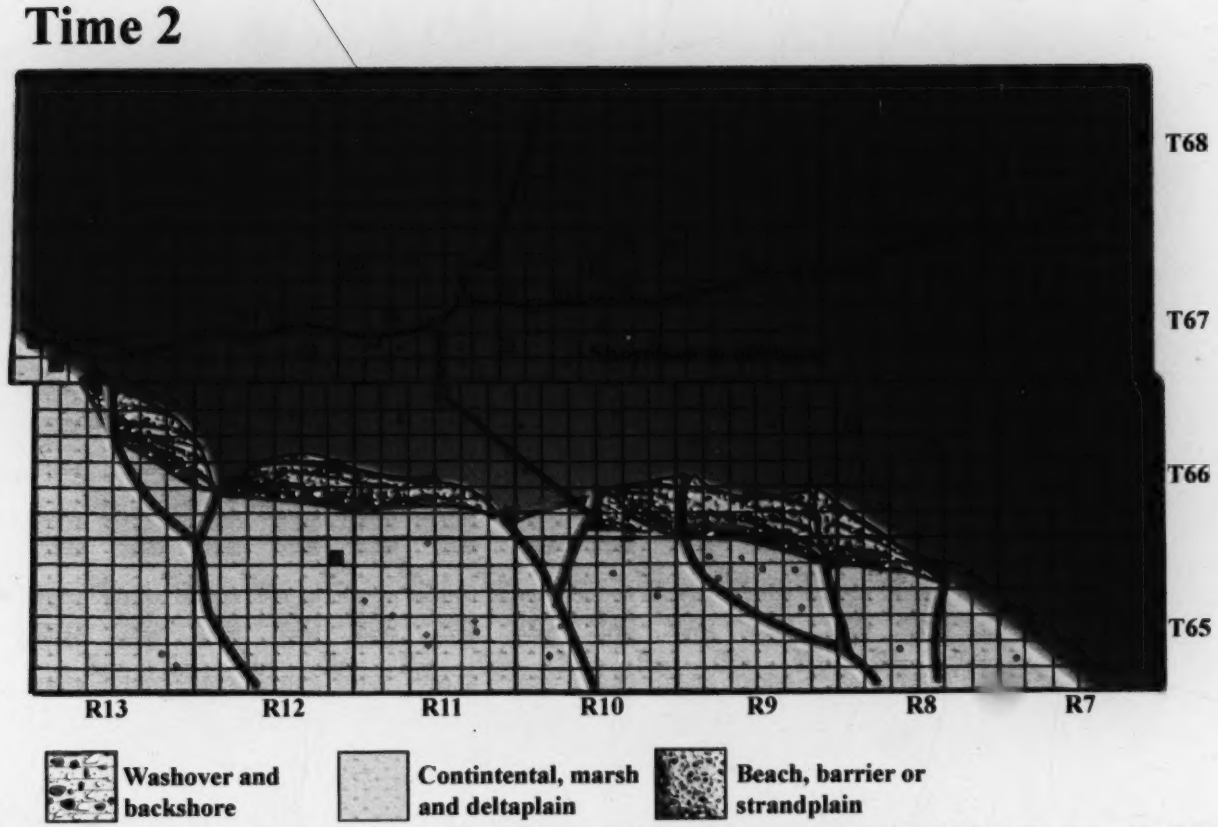



**Figure 3.3. Palaeogeography during the deposition of R1. After deposition of T1, a regressive strandplain unit was established. Palaeo-shoreline is inferred largely from the distribution of gross sand in this unit (APPENDIX II).**

deposits were recognized extensively and were found to trend approximately west to east, thinning in an easterly direction. These deposits extend westward almost to the Alberta – British Columbia border, where they are truncated by extensive channel deposits (Figure 3.5). Further to the west, conglomeratic beach deposits were not recognized in the regressive portion of the Notikewin (Leckie 1985). This strongly suggests that the source of conglomerate for the beach and uppershoreface was the channel mapped in Figure 2.17. Lagoonal and estuarine deposits were recognized both on top of, and shoreward (south) of beach deposits in this unit.

The succession of facies (Figure 3.6) is consistent with a progradational shoreface model, and the presence of the estuarine together with the lagoon sediments establish that the unit had a barrier configuration. Longshore current that modified the sediments discharged from fluvial channels resulted in the growth of this unit (Figure 3.4). Progradation of the Notikewin R2 is shown to be minimal, given that beach sediments are recognized over a distance of approximately 5 kilometers in a shore normal direction.

The configuration of the R2 deposits are consistent with a progradational barrier spit, which grew from headlands in the western portion of the study area. Sea level at this time would be rising, otherwise the estuary behind the barrier would rapidly fill in (Roy *et al.* 1994).

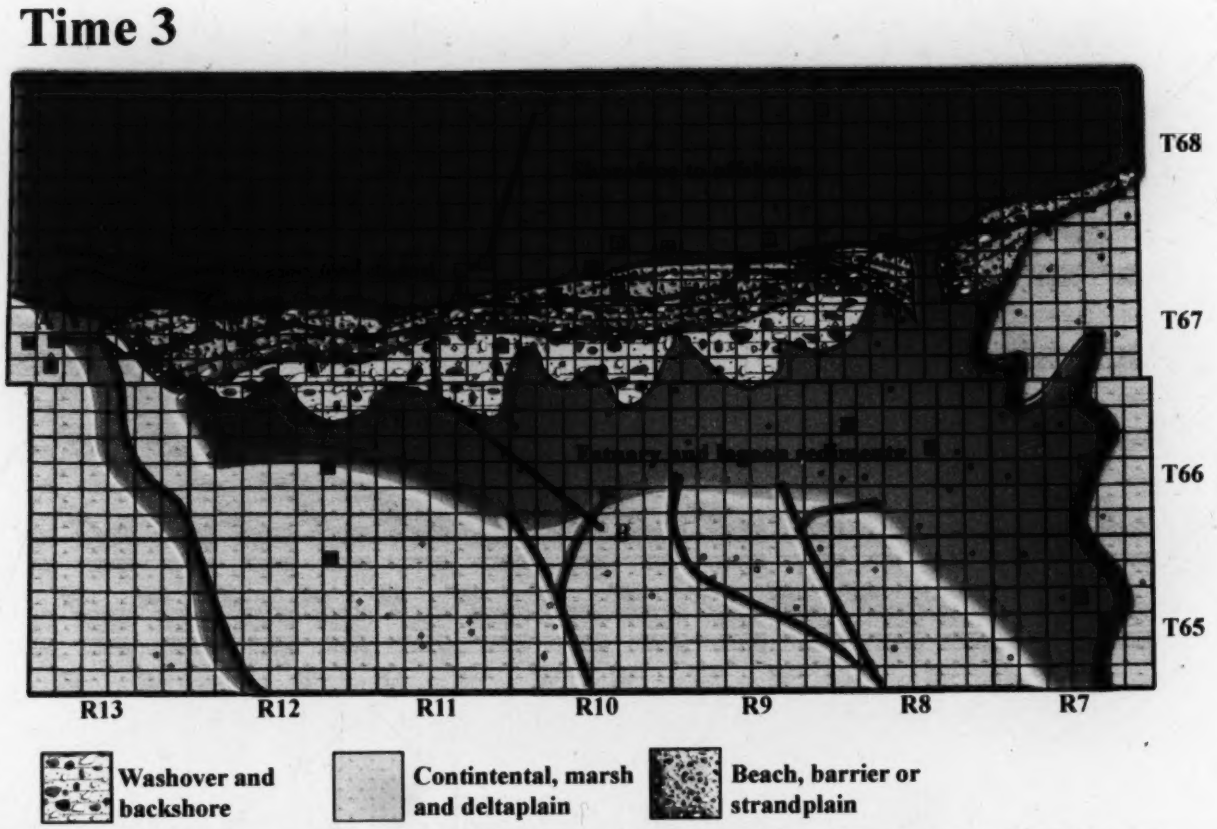



**Figure 3.4. Palaeogeography during deposition of R2. Sediment introduced from a channel in the west of the study area resulted in the development of a barrier-spit which migrated longshore towards the east. Extensive lagoon and estuary sediments were deposited shoreward of this barrier, eroding into deposits of R1.**

OVER SIZED PAGE REMOVED

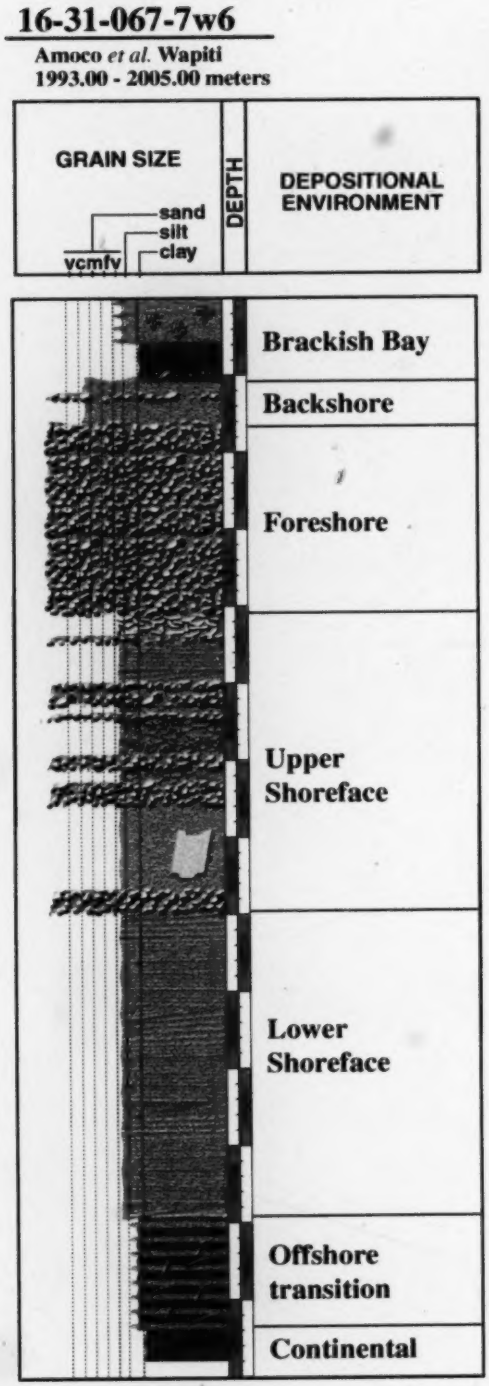



**Figure 3.6. Succession of facies through the Notikewin R2 depositional succession. This location is one of the few locations where an entire depositional sequence has been cored. The division between the upper and lower shoreface as seen in this core is quite typical, and displays a sharp grainsize variation above and below the contact. This type of contact is similar to that described as a regressive surface of erosion in other studies, however here it is attributed to storm activity and rip current generation in a conformable depositional sequence.**

Notikewin R3:

The final sequence recognized within the study area unconformably overlies shoreface sediments of the R2. The contact between the two is recognized by a change in depositional environments from marine or marginal marine (R2) to continental (R3). Within the study area this unit is entirely continental in nature, however a marine sequence is present to the north of the study area and was observed in a core from wellbore 07-30-72-13w5. These deposits represent a relative drop in sea level and a progradation of the shoreline by approximately 50 kilometers. A schematic representation of the palaeogeography during this time is portrayed in figure 3.7. The upper boundary of this unit is marked by a deepening of sea level and the encroachment of the Harmon sea.

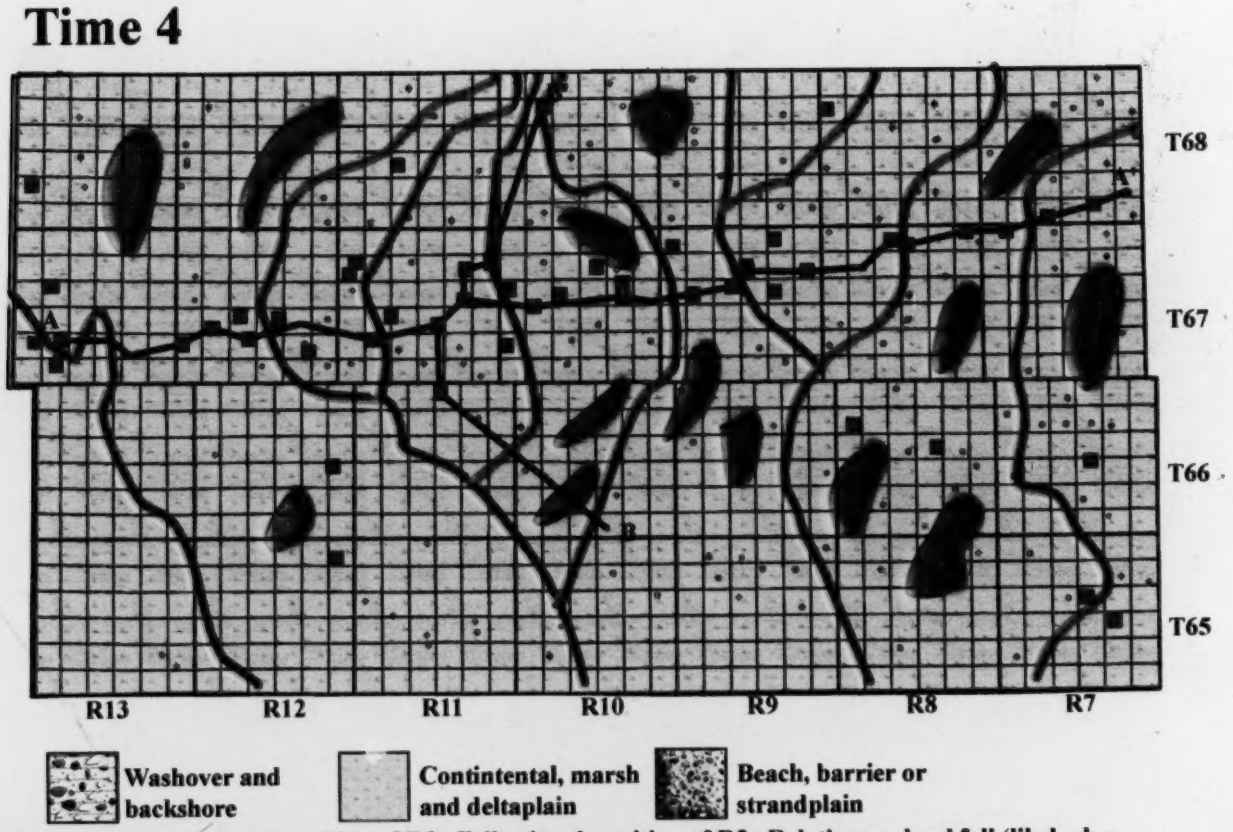



**Figure 3.7. Palaeogeography during deposition of R3. Following deposition of R2, Relative sea level fall (likely due to increased sediment supply) resulted in movement of the shoreline basinward of the study area and the deposition of continental, marsh and deltaplain sediments.**

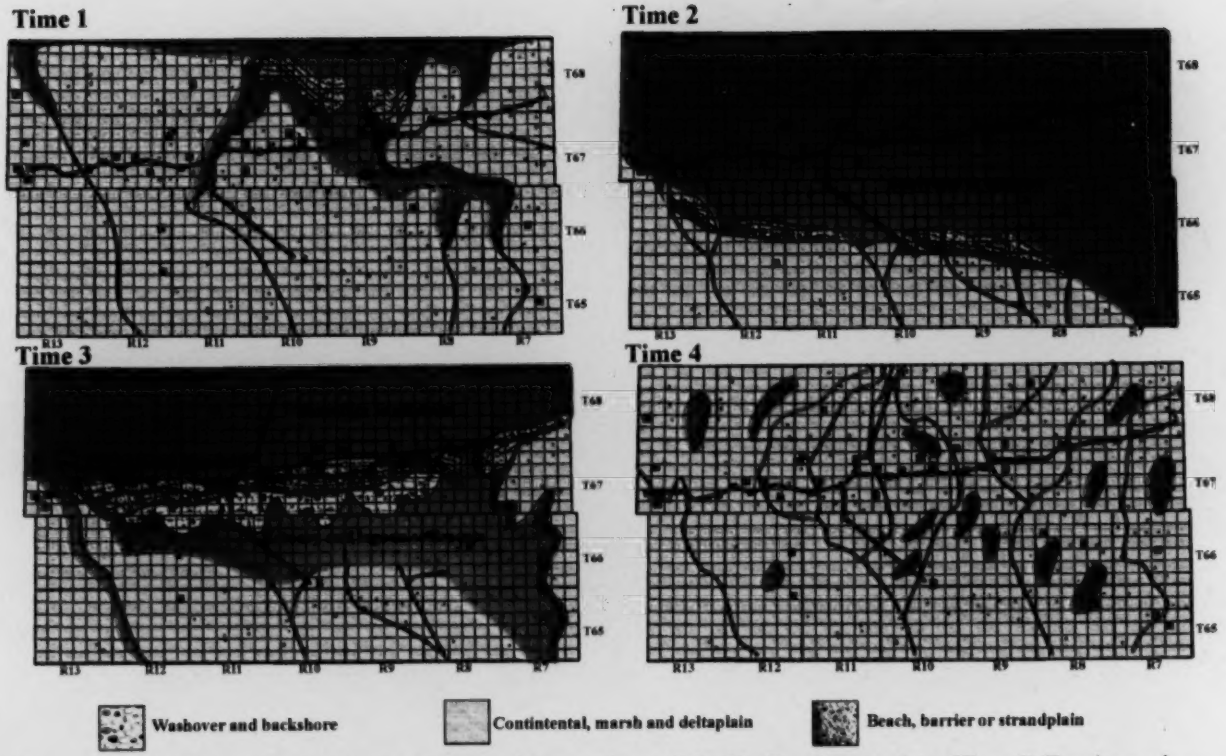



**Figure 3.8. Summary of palaeogeography for depositional successions of the Notikewin member. Time 1) Transgression following Falher deposition results in an estuarine coastline. Time 2) A regressive wave dominated strand plain to deltaic unit progrades from south to north. Time 3) A barrier spit grows by longshore drift of sediments discharged from a fluvial channel in the western portion of the study area. Time 4) A relative sea level fall occurs resulting in the progradation of the shoreline to the north of the study area**

# CHAPTER 4

## CONCLUSIONS

1) The Notikewin Member in the study area is a complicated unit which contains 4 distinct depositional sequences. What was previosly thought to be a single coarsening upward cycle is in actuality several different units which have been amalgamated through storm activity resulting in the apparent appearance of a single unit. It is only though the detailed mapping of facies that these units may be seperated from each other, as the bounding discontinuites are often obscured.

2) The "sharp based" or "forced regressive" shoreface model was shown to not be applicable for explaining stratal paterns in the Notikewin Member. This study demonstrates that surfaces that can be explained by depositional mechanisms inherent to a high energy shoreface system. Any sharp based unit in high energy deposits that is thought to represent a stratigraphically significant boundary should be examined with great care with regards to the depositional processes.

3) The Notikewin did not likely prograde a great distance while maintaining a barrier configuration as was thought by previous authors (Leckie, 1985; Smith 1984). This misunderstanding resulted from regarding the Notikewin as a single sequence rather then several distinct depositional successions.

**Discussion:**

Reconstructions of the palaeogeography of the Notikewin Member in the study area demonstrate that several shoreline sequences developed, each with very different orientations. Several past interpretations of Notikewin Member palaeogeography have generally referred to a northeast to southwest trending barrier system that spans across nearly the entire width of the basin (e.g. Jackson, 1984; Smith, 1994). Such reconstruc-

tions do not take into account the overall shape of the basin during the Albian that has been established by earlier workers (Jeletzky, 1971; Williams and Stelck, 1975) (see figure 1.7). In addition, these palaeogeographic reconstructions portray shorelines extending into areas that have been interpreted as already being zones of mountain building during the early Cretaceous. It is unlikely that Notikewin era shorelines would extend directly into these areas without some deflection of the trend portrayed. Given a seaway extent similar to that shown in figure 1.7, one would expect that the shoreline would begin to trend in a North to South direction in the western portions of the palaeo-seaway. A relatively small area was examined in this study, so even though the Notikewin R2 demonstrates a local shoreline trending in the same direction as reconstructions from Jackson (1984) and Smith (1994), this should not be taken as confirmation of the overall orientation of the shoreline. By sub-dividing the Notikewin and equivalents in other areas using a method similar to that used here, it may be possible to resolve these discrepancies.

**References:**

Aigner, T. 1985. Storm depositional systems. In: G.M. Friedman, H.J. Neugebauer and A. Seilacher (eds.), Lecture Notes in Earth Sciences. Springer-Verlag, 174 p.

Ainsworth, B.R. 1992. Sedimentology and Sequence Stratigraphy of the upper Cretaceous, Bearpaw - Horseshoe Canyon Transition, Drumheller, Alberta. A.A.P.G Annual Convention Field Guide, 118 p.

Alberta Energy and Utilities Board. 1997. Alberta's Reserves 1997; crude oil, oil sands, gas, natural gas liquids, sulphur December 1997.

Allen, J.R.L. 1982. Sedimentary structures. Their character and physical basis. Developments in Sedimentology, 30, 663 p.

Armitage, I.A. 2002. Sedimentology, Ichnology, and High-Resolution Allostratigraphy of the Falher "C" Member, Spirit River Formation, west-central Alberta, Canada. Unpublished M.Sc. Thesis, University of Alberta, 178 p.

Arnott, R.W.C. 1993. Sedimentological and sequence stratigraphic model of the Falher "d" Pool, Lower Cretaceous, northwestern Alberta. Bulletin of Canadian Petroleum Geology 41, 4: 456-463.

Arnott, R.W.C. 1994. The Falher 'D' Pool. Lower Cretaceous Northwestern Alberta – sedimentological and sequence stratigraphic framework. In S.G. Pemberton, D.P. James, and D.M. Wightman (eds.), Canadian Society of Petroleum Geologists Mannville Core Conference, p. 111-125.

Badgley, P.C. 1952. Notes on the Subsurface Stratigraphy and Oil and Gas Geology of the Lower Cretaceous Series in Central Alberta, Geological Survey of Canada Paper 52-11.

Bell, R. 1885. Report on part of the Basin of the Athabasca River, Northwest Territory. Geological Survey of Canada Progress Report 1885, 35p.

Bhattacharya, J.P. 1993. The expression and interpretation of marine flooding surfaces and erosional surfaces in core; examples from the Upper Cretacesou Dunvegan Formation, Alberta foreland basin, Canada. Special publication of the International Association of Sedimentology 18. 125-160

Bhattacharya, J.P. and R.G. Walker. 1991. Allostratigraphic subdivision of the Upper Cretaceous Dunvegan, Shaftesbury and Kaskapau formations in the northwestern Alberta subsurface. Bulletin of Canadian society of Petroleum Geologists 39:145-164.

Bourgeois, J. and E.L. Leithold. 1983. Sedimentation, tectonics and sea-level change as reflected in four wave dominated shelf sequences in Oregon and California. In: D.K. Larue and R.J. Steel (eds.), Cenozoic Margin Sedimentation, Pacific Margin, U.S.A. Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 1-16.

Bourgeois, J. and E.L. Leithold. 1984. Wave-worked conglomerates – depositional processes and criteria for recognition. In: E.H. Koster and R.J. Steel (eds.), Sedimentology of gravels and conglomerates. Canadian Society of Petroleum Geologists Memoir 10: 331-343.

Brekke, H.G. and S.G. Pemberton. 1994. Paleoenvironmental reconstruction of the Bluesky Formation in the Sinclair Field, West-Central Alberta: An Integrated Ichnological and Sedimentological Approach. In: S.G. Pemberton, D.P. James, and D.M. Wightman (eds.), Canadian Society of Petroleum Geologists Mannville Core Conference, p. 331-349.

Caddel, M.E. 1999. Sedimentology and stratigraphy of the Falher C Member, Spirit River Formation, northeastern British Columbia. Unpublished M.Sc. Thesis, University of Calgary, 242 p.

Caldwell, W.G.E., North, B.R., Stelck, C.R., and Wall, J.H. 1978. A foraminiferal zonal scheme for the Cretaceous System in the Interior plains of Canada. *In*: C.R. Stelck and B.D.E. Chatterton (eds.), Western and Arctic Canadian Biostratigraphy, Geological Association of Canada, Special Paper 18: 495-575.

Caldwell, W.G.E., Diner, R., Eicher, D.L., Fowler, S.P., North, B.R., Stelck, C.R., and Von Holdt Wilhelm, L. 1993. Foraminiferal Biostratigraphy of Cretaceous Marine Cyclothems. *In*: W.G.E Caldwell and E.G. Kauffman (eds.), Evolution of the Western Interior Basin, p. 477- 520.

Cant, D.J. 1984. Development of shoreline-self sand bodies in a Cretaceous epeiric sea deposit. Journal of Sedimentary Petrology 54, 2: 541-556.

Cant, D.J. 1988. Regional structure and development of the Peace River Arch, Alberta: A Paleozoic Failed-Rift System? Bulletin of Canadian Petroleum Geology 36; 3: 284-295.

Cant, D.J. 1994. Disconformities and Transgressive deposits within Falher Cycles-Elmworth Field. In S.G. Pemberton, D.P. James, and D.M. Wightman (eds.), Canadian Society of Petroleum Geologists Mannville Core Conference, p. 13-19.

Cant, D.J. 1995. Sequence stratigraphic analysis of individual depositional successions: Effects of marine-nonmarine sediment partitioning, and longitudinal sediment transport, Mannville Group, Alberta foreland basin, Canada. American Association of Petroleum Geologists Bulletin 79: 749-762.

Cant D.J. 1996. Sedimentological and sequence stratigraphic organization of a foreland clastic wedge, Mannville Group, western Canada basin. Journal of Sedimentary Research 66, 6: 1137-1147.

Cant, D.J. and Stockmal, G.S. 1989. The Alberta Foreland Basin: relationship between stratigraphy and Cordilleran terrane-accretion events. Canadian Journal of Earth Sciences 26: 1964 – 1975.

Carmichael, S.M.M. 1981. Depositional Environments and Paleocurrent Trends in the Gates Member, Northeast Coalfield. *In*: D. Bulinck (editor), Geological Fieldwork 1981. A Summary of Field Activities, p. 244-258.

Carmichael, S.M.M. 1983. Sedimentology of the Lower Cretaceous Gates and Moosebar formations, Northeast Coalfields, British Columbia. Unpublished Ph.D. thesis, University of British Columbia, 285 p.

Carmichael, S.M.M. 1988. Linear estuarine conglomerate bodies formed during a mid-Albian marine transgression; "Upper Gates" Formation, Rocky Mountain Foothills of North-Eastern British Columbia. In: D.P. James and D.A. Leckie (eds.), Sequences, stratigraphy, sedimentology: surface and subsurface. Canadian Society of Petroleum Geologists, Memoir 15: 49-61.

Clifton, H.E. 1981. Progradational sequences in Miocence shoreline deposits, southern Caliente Range, California. Journal of Sedimentary Petrology 51: 165-184.

Clifton, H.E. 2000. Shoreface myths and misconceptions, AAPG Annual Convention Abstracts

Clifton, H.E., R.E. Hunter, and R.L. Phillips. 1971. Depositional structures and processes in the non-barred high-energy nearshore. Journal of Sedimentary Petrology, 41: 651-670.

Clifton, H.E., and Thompson, J.K. 1978. *Macaronichnus segregatis* – a feeding structure of shallow marine polychaetes. Journal of Sedimentary Petrology, 48: 1293-1302.

Cooper, J.A.G. 1994. Lagoons and microtidal coasts. *In* R.W.G. Carter and C.D. Woodroffe (eds.), Coastal Evolution, Late Quaternary Shoreline Morphodynamics, Cambridge University Press, p. 219-265.

Curran, H.A. 1985. The trace fossil assemblage of a Cretaceous nearshore environment: Englishtown Formation of Delaware, U.S.A. In: H.A. Curran (editor), Society of Economic Paleontologists and Mineralogists Special Publication No. 35, Biogenic Structures, p. 261-276.

Dawson, G.M. 1881. Report on an exploration from Port Simpson on the Pacific coast to Edmonton on the Saskatchewan, embracing a portion of the Northern part of B.C. and Peace River Country, 1879. Geological Survey of Canada Progress Report 1879 – 1880, pt. 6, p. 1-142.

Devine, P.E. 1991. Transgressive origin of channeled estuarine deposits in the Point Lookout Sandston, Northwestern New Mexico: A model for Upper Cretaceous, cyclic regressive parasequences of the U.S. western interior. American Association of Petroleum Geologists Bulletin 75: 1039-1063

Dickenson, K.A., H.L. Berryhill, and C.W. Holmes. 1972. Criteria for recognizing ancient barrier coastlines. In: J.K. Rigby and W.K. Hamblin (eds.), Recognition of Ancient Sedimentary Environments. Society of Economic Mineralogists and Paleontologists, Special Publication 16: 192-214.

Dott, R.H. Jr. and J. Bourgeois. 1982. Hummocky stratification: significance of its variable bedding sequences. Bulletin of the Geological Society of America 93: 663-680.

Duke, W.L. 1985. Hummocky cross-stratification, tropical hurricanes, and intense winter storms. Sedimentology 32: 167-194.

Dupré, W.A. 1984. Reconstruction of paleo-wave conditions during the Late Pleistocene from marine terrace deposits, Monterey Bay, California. In: B. Greenwood and R.A. Davis Jr. (eds.), Hydrodynamics and sedimentation in wave-dominated coastal environments. Marine Geology 60: 435-454.

Elliot, T. 1986. Siliciclastic Shorelines. In: H.G. Reading (editor.), Sedimentary Environments and Facies, Blackwell Scientific Publications, Oxford, p.155-188.

Gardiner, S. 1982. Depositional Environment, Petrology, Diagenesis and Reservoir Aspects of the Notikewin Member, Fort St. John Group, West – Central Alberta, Unpublished B.Sc. thesis, McMaster University, 128 p.

Hancock, J.M. 1975. The Sequence of Facies in the Upper Cretaceous of Northern Europe compared with that in the Western Interior, Geological Association of Canada Special Paper 13: 83-118.

Haq, B.U., J. Hardebol and P.R.Vail. 1987. Chronology of fluctuating sea levels since the Triassic. Science 235: 1156-1167.

Hayes. M.O. 1967. Hurricanes as geological agents: Case studies of Hurricane Carla, 1961 and Cindy, 1963. Bureau of Economic Geology, University of Texas Report of Investigations 61: 1-56.

Hayes, B.J.R., Christopher, J.E., Rosenthal, L., Los, G., Mckercher, B., Minken, P., Tremblay, Y.M. and Fennell, J. 1994. Cretaceous Mannville Group of the Western Canada Sedimentary Basin. *In*: G. Mossop and I. Shetsen (eds.), Geological Atlas of the Western Canada Sedimentary Basin, p. 317 - 334

Howard, J.D. 1975 . The sedimentological significance of trace fossils. In: R.W. Frey, (editor.), The Study of Trace Fossils, Springer-Verlag, New York, p. 131-146

Hunter, R.E., H.E. Clifton, and R.L. Phillips. 1979. Depositional processes, sedimentary structures and predicted vertical sequences in barred nearshore systems, southern Oregon coast. Journal of Sedimentary Petrology, Vol. 49: p.411-726.

Irving, E., P.J. Wynne and B.R. Globerman. 1993. Cretaceous paleolatitudes and overprints of North American Craton. Geological Association of Canada Special Paper 39: 91-96.

Jackson, P.C. 1984. Paleogeography of the Lower Cretaceous Mannville Group of Western Canada. *In*: J.A. Master (editor), Elmworth-Case Study of A Deep Basin Gas Field, American Association of Petroleum Geologists Memoir 38: p. 49-78.

Jeletzky, J.A., 1971. Marine Cretaceous biotic provinces and paleogeography of western and Arctic Canada illustrated by a detailed study of ammonites. Geological Survey of Canada Paper 70-22, 92 p.

Jeletzky, J.A. 1978. Causes of Cretaceous oscillations of sea level in Western and Arctic Canada and some general geotectonic implications. Geological Survey of Canada, Paper 77-18, 44p.

Johnson, H.D. and C.T. Baldwin. 1996. Shallow clastic seas In: H.G. Reading (editor), Sedimentary Environments: Processes, Facies and Stratigraphy, Blackwell Science Limited, Oxford, p. 232-280.

Kauffman, E.G. 1984. Paleobiogeography and Evolutionary Response Dynamic in the Cretaceous Western Interior Seaway of North America. In: G.E.G. Westermann (editor), Jurassic-Cretaceous Biochronology and Paleogeography of North America, p. 273-306.

Kirk, R.M. 1980. Mixed sand and gravel beaches: morphology, processes and sediments. Progress in Physical Geography 4: 189-210.

Leckie, D.A. 1983. Sedimentology of the Moosebar and Gates formations (Lower Cretaceous). Unpublished Ph.D. thesis, McMaster University, Hamilton, Ontario, 515 p.

Leckie, D.A. 1985. The Lower Cretaceous Notikewin Member (Fort St. John Group), northeastern British Columbia; a progradational barrier island system. Bulletin of Canadian Petroleum Geology 33,1: 39-51.

Leckie, D.A. 1986. Rates, controls and sand-body Geometry of transgressive-regressive cycles: Cretaceous Moosebar and Gates Formations, British Columbia. American Association of Petroleum Geologists Bulletin 70: 516-535.

Leckie, D.A. 1989. An Ostrea Bioherm in the Cretaceous Notikewin member, British Columbia. *In*: H.H.J. Geldsetzer and G.E. Tebbutt (eds.), Reefs, Canada and Adjacent Area, Canadian Society of Petroleum Geologists, Memoir 13: 736-737.

Leckie, D.A. and R.G. Walker. 1982. Storm-and Tide-dominated shorelines in Cretaceous Moosebar-Lower Gates interval- Outcrop equivalents of Deep Basin gas trap in Western Canada. American Association of Petroleum Geologists Bulletin 66: 138-157.

Leckie, D.A., Potocki, D.J., and Visser, K. 1991. The Lower Cretaceous Chinkeh Formation. A frontier – type play in the Liard Basin of Western Canada. American Association of Petroleum Geologists Bulletin 75, 8: 1324 – 1352

MacEachern, J.A. 1994. Integrating ichnology with sedimentology: sequence stratigraphy and paleoenvironmental interpretation of the Viking and Peace River formations, west-central Alberta. Unpublished Ph.D. thesis, University of Alberta, 566p.

MacEachern, J.A. and S.G. Pemberton. 1992. Ichnological aspects of Cretaceous shoreface successions and shoreface variability in the western interior seaway of North America . *In*: S.G. Pemberton (editor), Applications of ichnology to petroleum exploration: a core workshop, 17: 57-84.

Martini, I.P., A. Cascell and A. Rau. 1995. The Manciano Sandstone: a shoreface deposit of Miocene basins of the Northern Apennines, Italy. Sedimentary Geology 99: 37-59.

Massari, F. and G.C. Parea. 1988. Progradational gravel beach sequences in a moderate- to high-energy, microtidal marine environment. Sedimentology 35: 881-913.

Massari, F. and G.C. Parea. 1990. Wave-dominated Gilbert-type gravel deltas in the hinterland of the Gulf of Taranto (Pleistocene, southern Italy). *In:* A. Collela and D.B. Prior (eds.), Coarse-grained deltas. International Association of Sedimentologists Special Publication 10: 311-331.

May, R.W. 1967. Geology of the Peace River, Viking, Joli Fou and "Notikewin" Formations, Kaybob Area, northern Alberta, Unpublished M.Sc. thesis, University of Alberta, 99p.

McConnell, R.G. 1893. Report on a portion of the district of Athabasca, comprising the country between Peace River and Athabasca River north of Lesser Slave Lake. Annual Report of the Geological Survey of Canada, 67 p.

McLearn, F.H. 1918. Peace River Section, Alberta. Geological Survey of Canada Summary Report 1917, pt. C, p. 14 – 21.

Mellon, G.B. and Wall, J.H. 1956. Foraminifera of the Upper McMurray and basal Clearwater Formations. Research Council of Alberta Report 72, 22 p.

Meyers, R.A., D.G. Smith, H.M. Jol., and C.D. Peterson. 1996. Evidence for eight earthquake-subsidence events detected with group-penetrating radar, Willapa barrier, Washington. Geology 24: 99-102.

Milne, A. 1940. The ecology of the Tamar Estuary, IV. The distribution of the fauna and flora on buoys. Journal of the Marine Biological Association of the United Kingdom, 24: 69 - 87.

Monger, J.W.H., and R.A. Price. 1979. Geodynamic evolution of the Canadian Cordillera – progress and problems. Canadian Journal of Earth Sciences 16, 770-791.

Monger, J.W.H. 1989. Overview of Cordilleran geology, In: R.D. Ricketts(editor), Western Canada Sedimentary Basin: Canadian Society of Petroleum Geologists, p. 79 – 104.

Morton, R.A. 1979. Temporal and spatial variations in shorline changes and their implications, examples from the Texas Gulf Coast. SEPM Journal 49: 1101-1111.

Moslow, T.F. and S.G. Pemberton. 1988. An integrated approach to the sedimentological analysis of some Lower Cretaceous shoreface and delta front sandstone sequences. In: D.P. James and D.A. Leckie (eds.), Sequences stratigraphy and sedimentology: surface and subsurface. Canadian Society of Petroleum Geologists Memoir 15: 373-386.

Nauss, A.W. 1947. Cretaceous Microfossils of the Vermilion Area, Alberta. Journal of Paleontology, 21, 4: pp. 329-343.

Niedoroda, A.W., D.J.P. Swift. and T.S. Hopkins. 1985. The shoreface. In: R.A. Davis (editor), Coastal Sedimentary Environments, 2nd edition, Springer-Verlag, New York, p. 533-624.

Nilsen, T.H. 1973. Facies relations in the Eocene Tejon Formation of the San Emigdio and western Tehachapi mountains, California. Annual meeting, Society of Economic Paleontologists and Mineralogists Anaheim, Guidebook Trip 2, p. 7-23.

Nio. S.D. and C. Yang. 1991. Diagnostic attributes of clastic tidal deposits: a review In: D.G. Smith, G.E. Reinson, B.A. Zaitlin and R.A. Rahmani (eds.), Clastic tidal sedimentology. Canadian Society of Petroleum Geologists Memoir 16: 3-29.

North, B.R., and Caldwell, W.G.E. 1975. Cretaceous foraminifera from Saskatchewan and Manitoba. Geological Survey of Canada Paper 74 – 38, 35p.

Nummedal, D. and D.J.P. Swift. 1987. Transgressive stratigraphy at sequence-bounding unconformities; some principles derived from Holocene and Cretaceous examples. SEPM Special Publication 41: 241-260.

Pemberton, S.G., MacEachern, J.A, and M.J. Ranger. 1992. Ichnology and event stratigraphy: the use of trace fossils in recognizing tempestites. In S.G. Pemberton (editor), Applications of ichnology to petroleum exploration: a core workshop. SEPM, p. 85-117.

Pemberton, S.G. and D.M. Wightman. 1992. Ichnological characteristics of brackish water deposits. In S.G. Pemberton (editor), Applications of ichnology to petroleum exploration: a core workshop. SEPM core workshop 17: 141-168.

Plint, A.G. 1988. Sharp based shoreface sequences and "offshore bars" in the Cardium Formation of Alberta: Their relationship to relative changes in sea level. In C.K. Wilgus, B.S. Gastings, C.G.St.C. Kendall, H.W. Posamentier, C.A. Ross and J.C. Van Wagoner (eds.), Sea-Level Changes: An Integrated Approach. SEPM Special Publication 42: 357-370.

Plint, A.G. 1991. High-frequency relative sea level oscillations in Upper Cretaceous shelf clastics of the Alberta Foreland Basin: Possible evidence for a glacio-eustatic control?. In: D.I.M. MacDonald (editor), Sea Level Changes at Active Margins, International Association of Sedimentologists Special Publication 42: 109-124.

Plint, A.G. 1996. Marine and nonmarine systems tracts in forth-order sequences in the Early-Middle Cenomanian, Dunvegan Alloformation, northeastern British Columbia, Canada. In: J.A. Howell and J.F. Aitken (eds.), High Resolution Sequence Stratigraphy: Innovations and Applications. Geological Society Special Publication 104: 159-191.

Porter, J.W., R.A. Price and R.G. McCrossan. 1982. The Western Canada Sedimentary Basin. Philosophical Transactions of the Royal Society of London A305: 169-193.

Posamentier, H.W., H.W. Allen, D.P. James and M. Tesson. 1992. Forced regressions in a sequence stratigraphic framework: concepts, examples and sequence stratigraphic significance. American Association of Petroleum Geologists Bulletin 76: 1687-1709.

Posamentier, H.W. and G.P. Allen. 1999. Siliciclastic Sequence Stratigraphy – Concepts and Applications. SEPM Concepts in Sedimentology and Paleontology 7, 210p.

Rahmani, R.A. and D.G. Smith. 1988. The Cadotte Member of northwestern Alberta: a high energy barred shoreline. In: D.P. James and D.A. Leckie (eds.), Sequences,

Stratigraphy, Sedimentology: Surface and Subsurface. Canadian Society of Petroleum Geologists, Memoir 15: 431-438.

Reading, H.C. and J.D. Collinson. 1996. Clastic Coast. In: H.G. Reading (editor), Sedimentary Environments: Processes, Facies and Stratigraphy. Blackwell Science Limited, Oxford, p. 154-231.

Reinson, G.E. 1984. Barrier-island and associated strand-plain systems. In: R.G. Walker (ed.) Facies models, 2nd edition, Geoscience Canada, Reprint Series 1, Geological Association of Canada, St. John's, p. 119-140.

Rosenthal, L.R.P. and R.G. Walker. 1987. Lateral and vertical facies sequences in the Upper Cretaceous Wapiabi Formation, southern Alberta. Canadian Journal of Earth Sciences 24: 771-783.

Rouble, R.G. and R.G. Walker. 1994. High resolution sequence stratigraphy and depositional environments of the Falher Members A and B, Lower Cretaceous Spirit River Formation of Northwestern Alberta. In: S.G. Pemberton, D.P. James and D.M. Wightman (eds.), Canadian Society of Petroleum Geologists Mannville Core Conference, p. 1-12

Rouble, R.G. and R.G. Walker. 1997. Sedimentology, high-resolution allostratigraphy, and key stratigraphic surfaces in Falher members A and B, Spirit River Formation, West-Central Alberta. In: S.G. Pemberton and D.P. James (eds.), Petroleum geology of the Cretaceous Mannville Group, Western Canada. Canadian Society of Petroleum Geologists, Memoir 18: 1-29.

Roy, P.S, P.J. Cowell, M.A. Ferland and B.G. Thom. 1994. Wave-dominated coasts. In R.W.G. Carter and C.D. Woodroffe (eds.), Coastal Evolution, Late Quaternary Shoreline Morphodynamics, Cambridge University Press, p. 91-186.

Ruby, E.G., and Fox, D.L. 1976. Anaerobic respiration in the polychaete *Euzonus* (Thoracohelia) *mucronata*. Marine Biology 35, 2:149-153

Saunders, T.D.A. 1989. Trace fossils and sedimentology of a late cretaceous progradational barrier island sequence: Bearpaw-Horseshoe Canyon Formation transition, Dorothy, Alberta. Unpublished M.Sc. Thesis, University of Alberta, 187 p.

Saunders, T., J.A. MacEachern. and S.G. Pemberton. 1994. Cadotte Member sandstone: progradation in a boreal basin prone to winter storms. In: S.G. Pemberton, D.P. James and D.M. Wightman (eds.), Canadian Society of Petroleum Geologists Mannville Core Conference, p. 331-349

Selwyn, A.R.C. 1878. Summary Report of Geological Investigations, Geological Survey of Canada Progress Report 1877, p. 1 – 27

Singh, C. 1971. Lower Cretaceous Microfloras of the Peace River Area, Northwestern Alberta. Research Council of Alberta Bulletin 28, 542 p.

Smith, R.D. 1984. Gas Reserves and Production Performance of the Elmworth /Wapiti Area of the Deep Basin. In: J.A. Masters (editor), Elmworth-Case Study of A Deep Basin Gas Field, American Association of Petroleum Geologists Memoir 38: 153-172.

Smith, D.G. 1994. Paleogeographic Evolution of the Western Canada Foreland Basin In G. Mossop and I. Shetsen (eds.), Geological Atlas of the Western Canada Sedimentary Basin, p. 277 – 296.

Stelck, C.R., J.H. Wall., W.G. Bahan and L.J. Martin. 1956. Middle Albian Foraminifera from Athabasca and Peace River drainage areas of western Canada. Research Council of Alberta, Report 75, 60 p.

Stelck, C.R., and Kramers, J.W. 1980. *Freboldicera* from the Grand Rapids Formation of north-central Alberta: Bulletin of Canadian Petroleum Geology 28: 509 – 521.

Stelck, C.R. and D.A. Leckie. 1990. Biostratigraphic constraints and depositional environment of the Lower Cretaceous (Albian) Boulder Creek Formation, Monkman area, northeastern British Columbia. Canadian Journal of Earth Sciences 28: 452-458.

Stott, D.F. 1968, Lower Cretaceous Bullhead and Fort St. John Groups between Smoky and Peace Rivers, Rocky Mountain foothills, Alberta and British Columbia: Geological Survey of Canada Bulletin 152, 279 p.

Stott, D.F. 1982. Lower Cretaceous Fort St. John Group and Upper Cretaceous Dunvegan Formation of the foothills and plains of Alberta, British Columbia, District of Mackenzie and Yukon Territory. Geological Survey of Canada Bulletin 328, 124 p.

Underschultz, J.R. 1991. Tectonic loading, sedimentation, and sea-level changes in the foreland basin of north-west Alberta and north-east British Columbia, Canada. Basin Research 3: 165-174.

Van Wagoner, J.C., R.M. Mitchum, K.M. Campion, and V.D. Rahmanion. 1990. Siliclastic sequence stratigraphy in well logs, cores and outcrops. American Association of Petroleum Geologists, Methods in Exploration Series No. 7: 55 p.

Vos, R.G. and D.K. Hobday. 1977. Storm beach deposits in the late Palaeozoic Ecca Group of South Africa. Sedimentary Geology 19: 217-232.

Walker, R.G. and A.G. Plint. 1992. Wave- and shallow-marine systems. In: R.G. Walker and N. James (eds.), Facies models: response to sea level change. Geological Association of Canada, St. John's, p. 219-238.

Weimer, R.J. 1988. Record of relative sea-level changes; Cretaceous of Western Interior, U.S.A. In: C.K. Wilgus, B.S. Hastings, C.A. Ross, H. Posamentier, J. VanWagoner, and G St. C. Kendell-Christopher. Sea-level changes; an integrated approach. SEPM special publication 42: 285-288.

Wickenden, R.T.D. 1951. Some Lower Cretaceous sections on Peace River below the mouth of Smoky River, Alberta. Geological Survey of Canada Paper 51-16, 47 p.

Williams, G.D., and C. R. Stelck, 1975. Speculations on the Cretaceous Paleogeography of North America. In: W.G.E. Caldwell (editor), The Cretaceous System in the Western Interior of North America: Geological Association of Canada Special Paper 13: 1 – 20.

Workman, L.E. 1954. Lower Cretaceous of the Peace River Region In: Western Canada Sedimentary Basin- A symposium. American Association of Petroleum Geologists Ralph Leslie Rutherford Memorial Volume, p. 268-278.

# APPENDIX 1: CORE LITHOLOGS

The following appendix contains a representative portion of the cores that were logged as part of this study.

**Legend:**

Sharp — Scoured — Bioturbated — Uncertain

Undulating — Faulted — Inclined — Stylolite

Firmground — Hardground

## PHYSICAL STRUCTURES

- Current Ripples
- Climbing Ripples
- Low Angle Tabular Bedding
- Lenticular Bedding
- Convolute Bedding
- Graded Bedding
- Mud Cracks
- Double Mud Drapes
- Imbrication
- Gutter Casts
- Wood Molds
- M.S.C. - -
- 240 Pebble Stringer
- Floating Pebble
- Ball & Pillow Structures
- Frac - Fracture
- -2 Trough Cross-strat.
- Planar Bedding
- Flaser Bedding
- Herringbone Cross-strat.
- Chaotic Bedding
- Reverse Graded Bedding
- Synaeresis Cracks
- Load Casts
- Stylolites
- Pebble Stringer
- M - Massive bed
- S.M.C. - -
- Floating Pebbles
- Pebble Lag
- Subaqueous Wave Ripples
- MASSIVE - Massive Sandstone
- Oscillatory Ripples
- High Angle Tabular Bedding
- Wavy Parallel Bedding
- Hummocky Cross-strat.
- Scour
- Fault
- Reactivation Surface
- Tight zone
- Slickensides
- Swaley Cross Stratification
- C.S.C. - -
- ? - -Something to check
- Planar Bedding
- Ripple
- Cone-in-Cone Structure(s)
- G.C - Gutter Cast

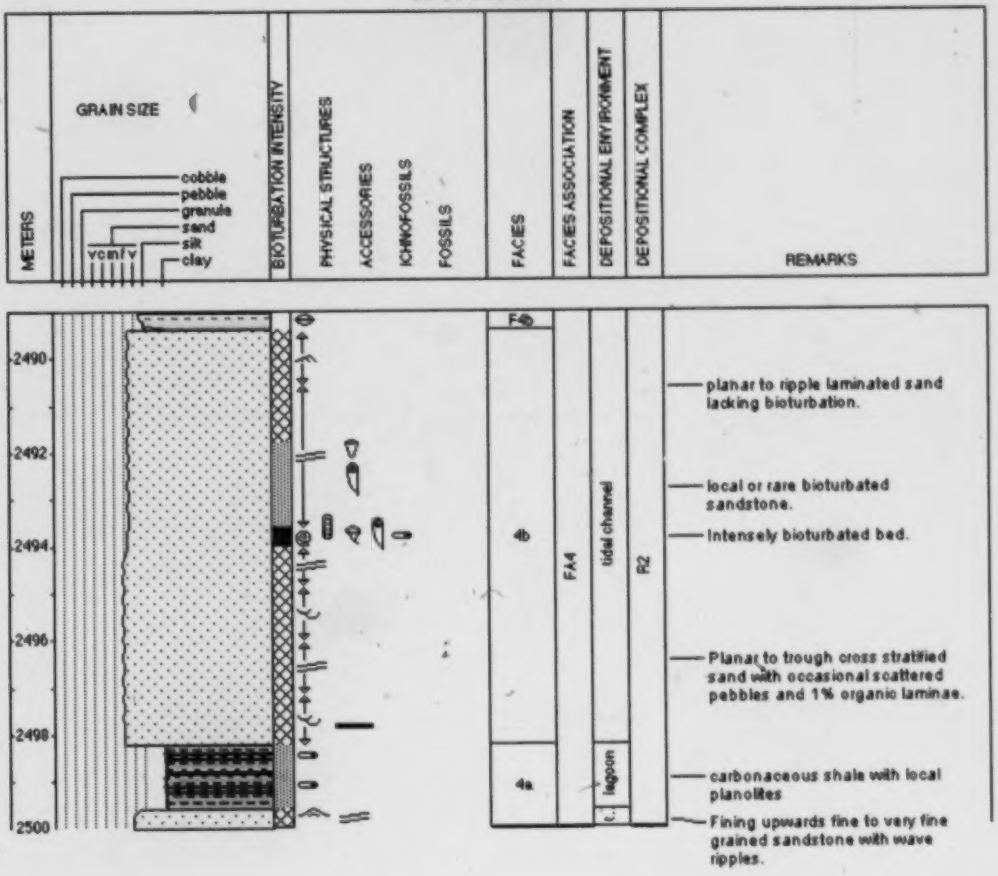
## LITHOLOGIC ACCESSORIES

- Sand Lamina
- Pebbles/Granules
- Organic Shale Lamina
- Sid - Siderite
- Gl - Glauconitic
- Cherty
- Fe - Ferruginous
- Wood Fragments
- Ch - Chlorite
- Q - Quartz Crystals
- Grapestone
- Peloids
- Plant Fragments
- Shell Hash Bed
- Silt Lamina
- Coal Lamina
- Calcareous
- Bentonite
- Fld - Feldspathic
- Kaol - Kaolinitic
- Rip Up Clasts
- Shell Fragments
- Mc - Micaceous
- Oolitic
- Coated Grains
- Anhydritic
- Brach Shell Hash
- Shale Lamina
- Breccia Horizon
- Dolomitic
- Sm - Smectite
- Lith - Lithic
- Py - Pyrite
- Coal Fragments
- Paleosol Horizon
- S - Sulfur
- Pisolites
- Fecal Pellets
- Pyritized horizon
- Brach Shells

## ICHNOFOSSILS

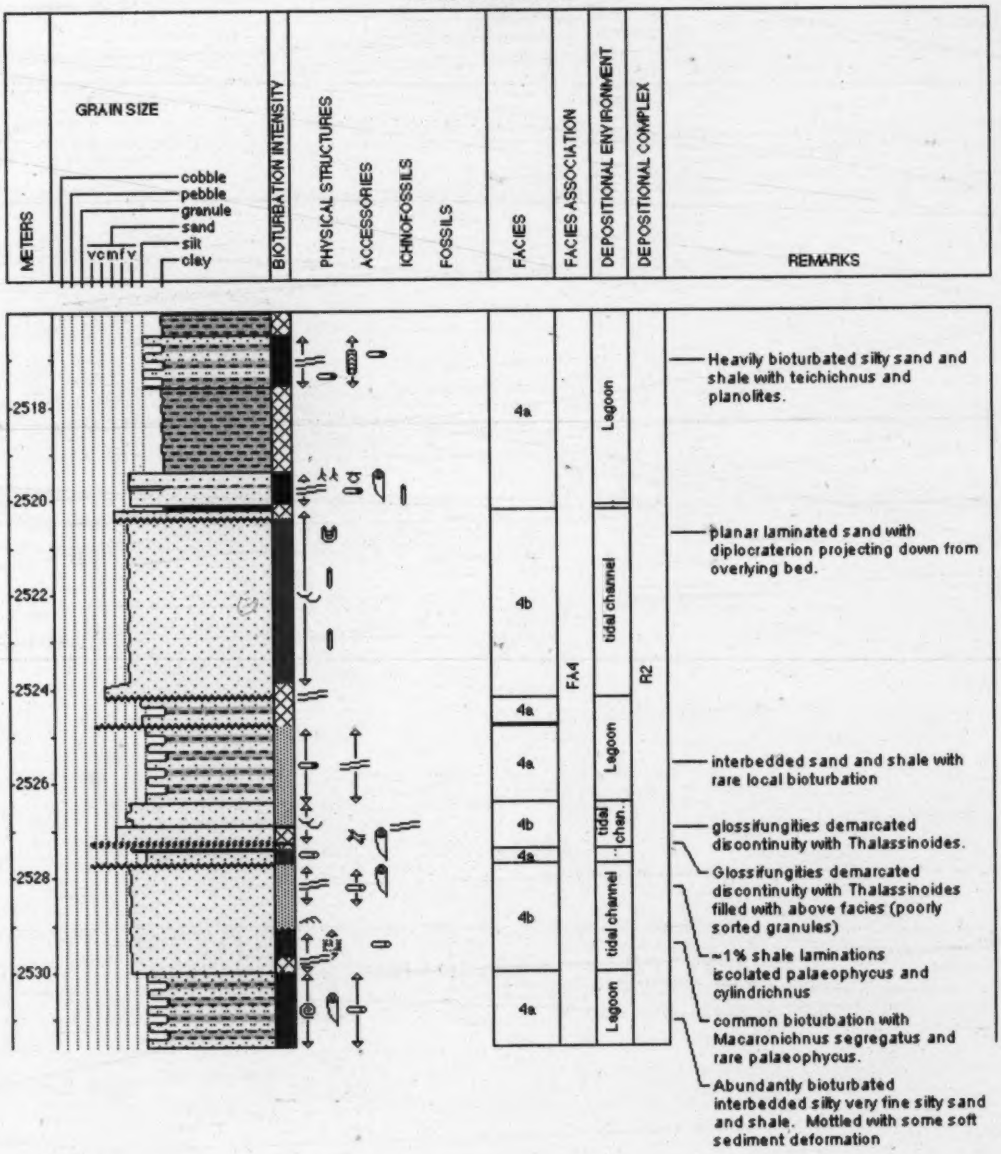
- Rootlets
- Planolites
- Diplocraterion
- Ophiomorpha
- Rhizocorallium
- Conichnus
- Asterosoma
- Chondrites
- Zoophycos
- Tryparites
- Scolicia
- Skolithos
- Palaeophycus
- Arenicolites
- Escape Trace
- Cylindrichnus
- Conostichus
- Rosselia
- Terebellina
- Helminthopsis
- Bored HardGround
- Lockeia
- Monocraterion
- Gyrolithes
- Macaronichnus
- Trichichnus
- Bergaueria
- Psilonichnus
- Thalassinoides
- Teichichnus
- Teredolites
- Anconichnus

**Ulster Tailsman Bilbo**
**11-14-065-07w6**



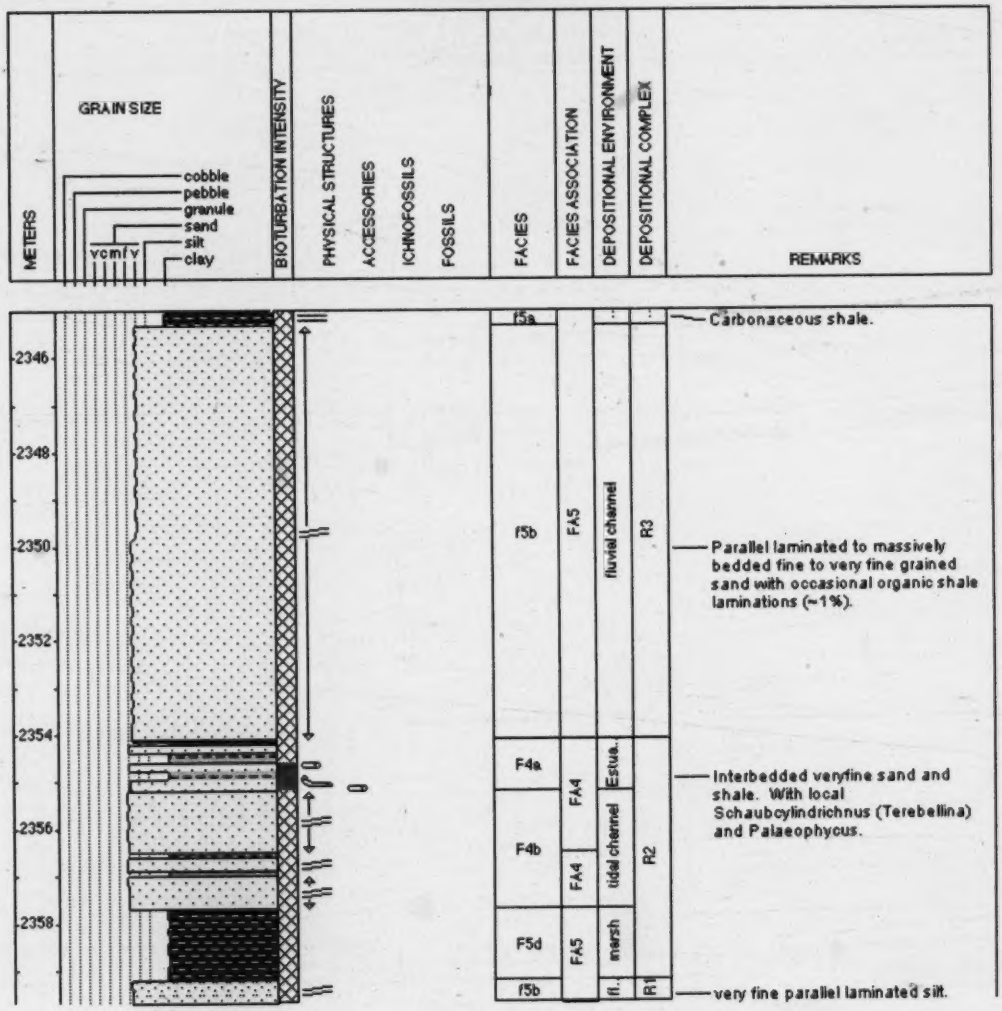
**Ulster Talisman Bilbo**

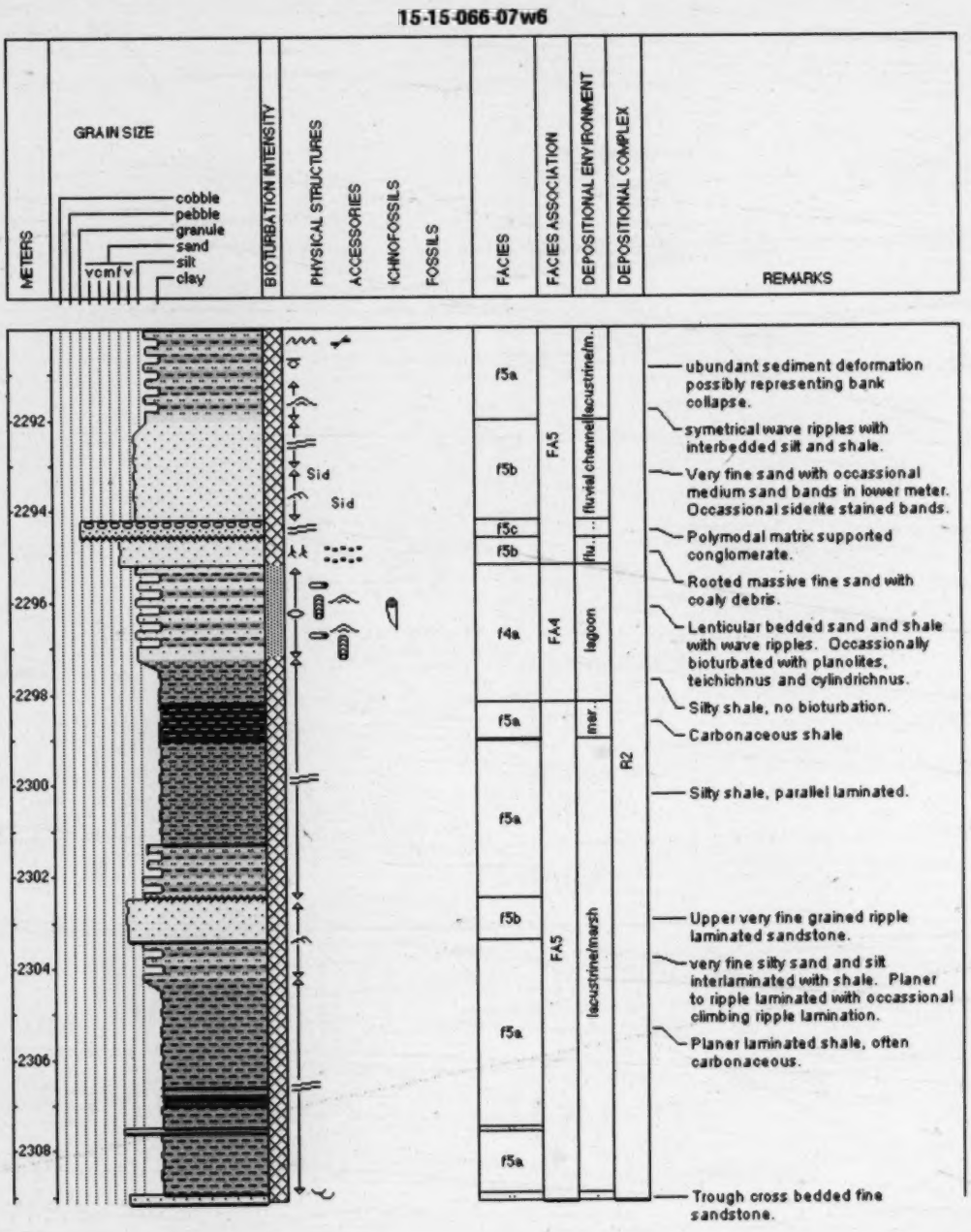
**11-22-065-07w06**



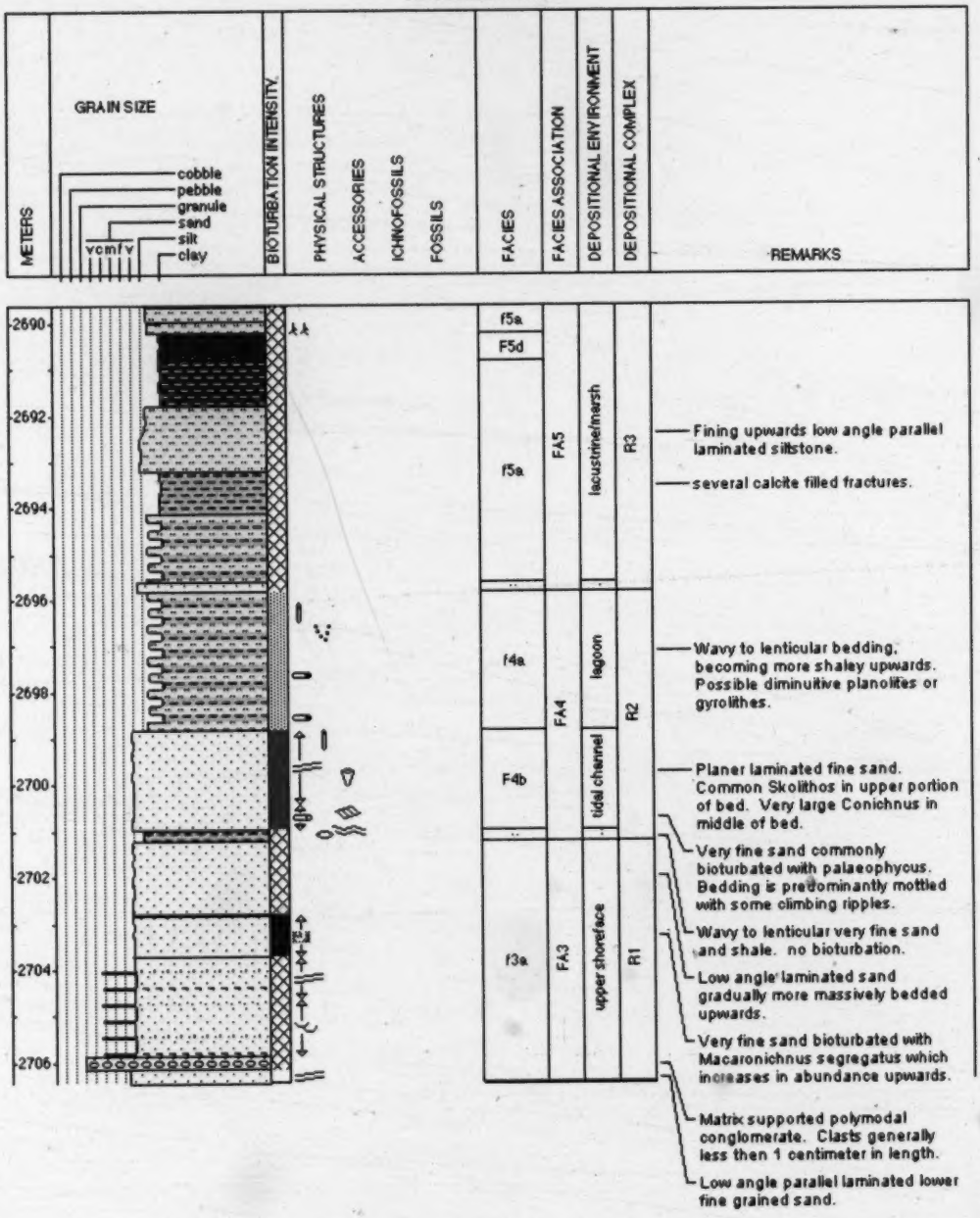
**Canhunter et al Wapiti**

**07-30-066-08w06**

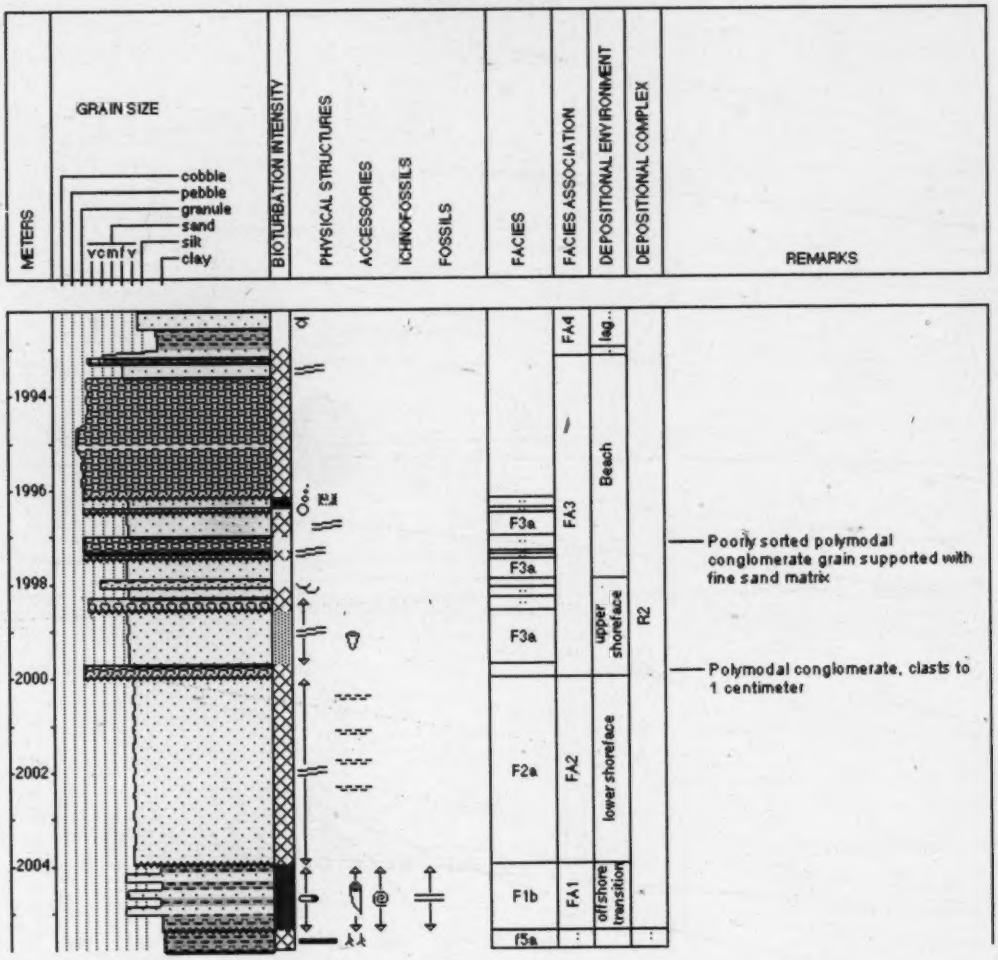



15-15-066-07w6
METERS
GRAIN SIZE
cobble
pebble
granule
sand
silt
clay
vcmfv
BIOTURBATION INTENSITY
PHYSICAL STRUCTURES
ACCESSORIES
ICHNOFOSSILS
FOSSILS
FACIES
FACIES ASSOCIATION
DEPOSITIONAL ENVIRONMENT
DEPOSITIONAL COMPLEX
REMARKS
2292
2294
2296
2298
2300
2302
2304
2306
2308
Sid
Sid
f5a
f5b
f5c
f5b
f4a
f5a
f5a
f5b
f5a
f5a
FA5
FA4
FA5
fluvial channel/lacustrine/m.
flu...
lagoon
inter.
lacustrine/marsh
R2
ubundant sediment deformation possibly representing bank collapse.
symetrical wave ripples with interbedded silt and shale.
Very fine sand with occassional medium sand bands in lower meter. Occassional siderite stained bands.
Polymodal matrix supported conglomerate.
Rooted massive fine sand with coaly debris.
Lenticular bedded sand and shale with wave ripples. Occassionally bioturbated with planolites, teichichnus and cylindrichnus.
Silty shale, no bioturbation.
Carbonaceous shale
Silty shale, parallel laminated.
Upper very fine grained ripple laminated sandstone.
very fine silty sand and silt interlaminated with shale. Planer to ripple laminated with occassional climbing ripple lamination.
Planer laminated shale, often carbonaceous.
Trough cross bedded fine sandstone.

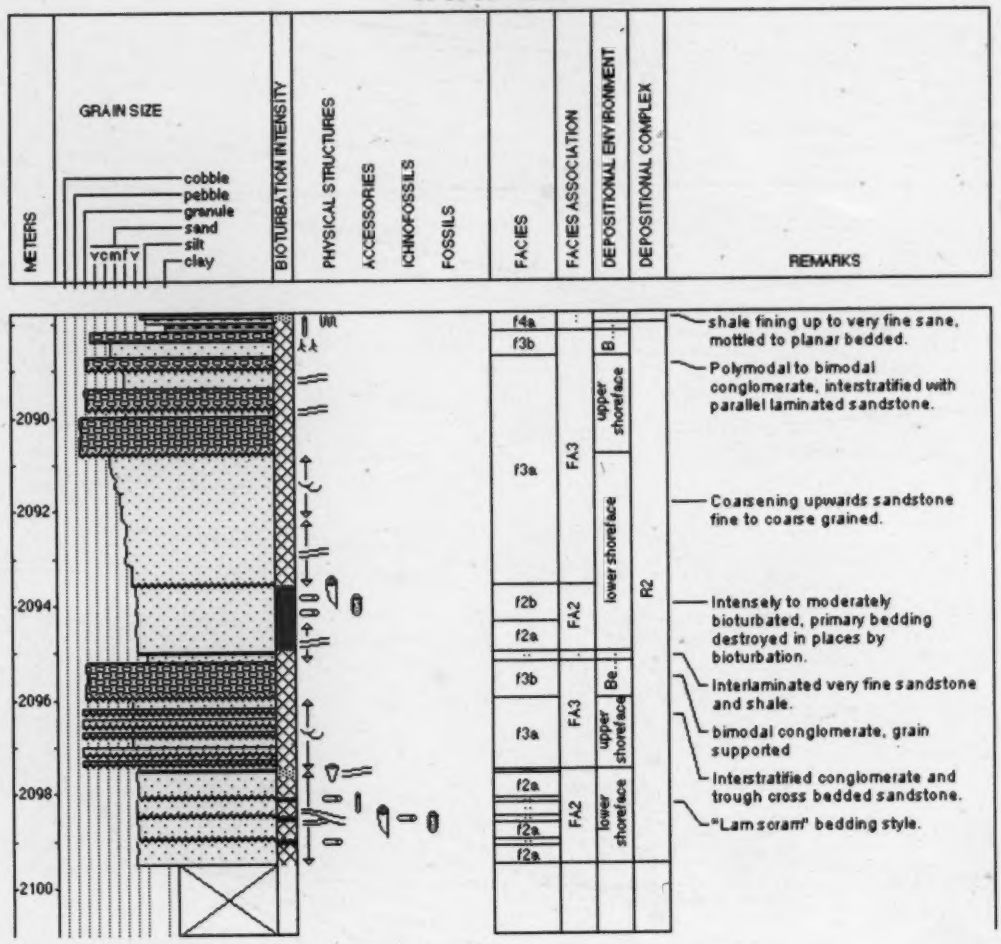
**Canhunter Wapiti**
**13-13-066-12w6**



**Amoco et al Wapiti**
**16-31-067-11w6**

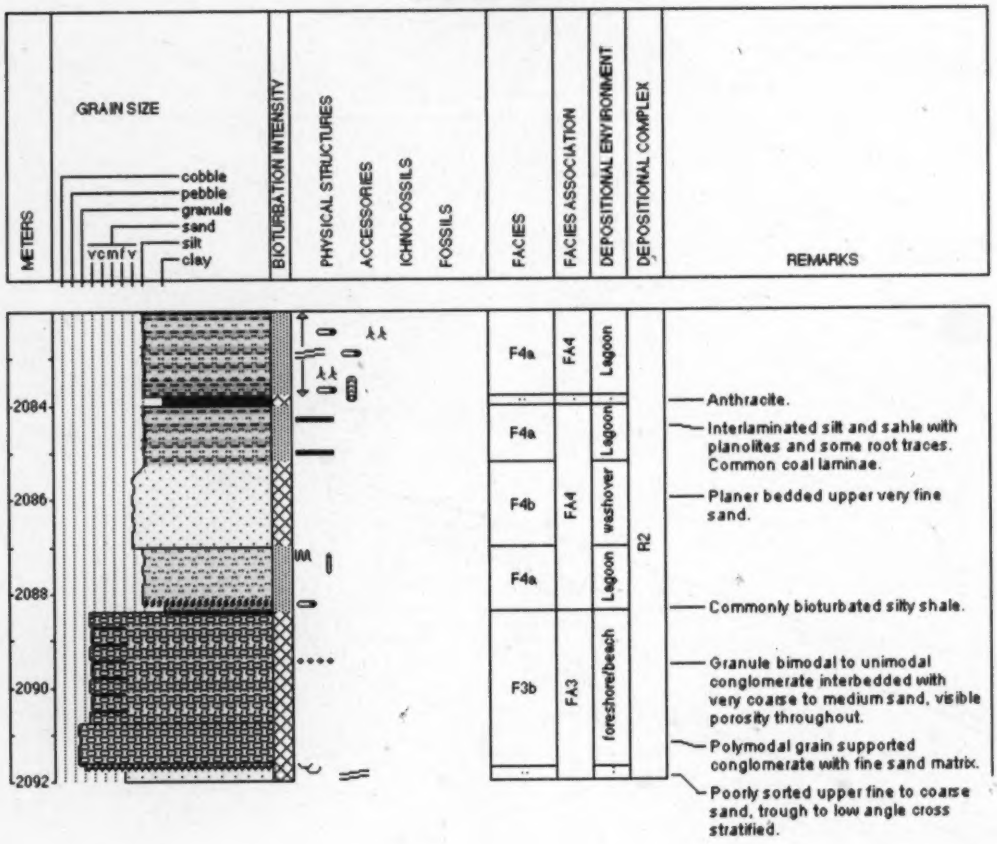


**Amoco et al. Wapiti**
**07-33-067-08w6**



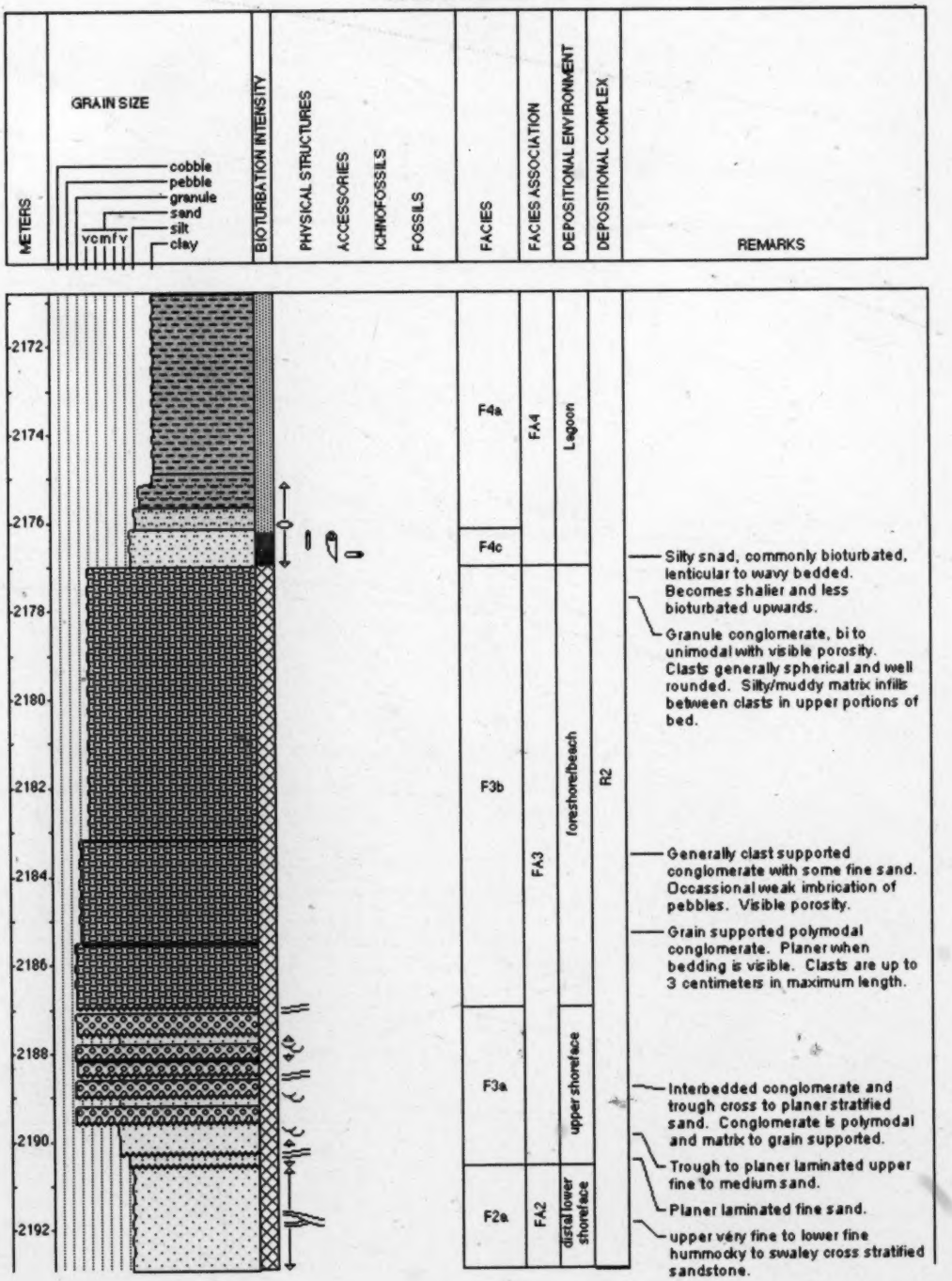
**Amoco et. al. Wapiti**

**04-34-067-08w6**



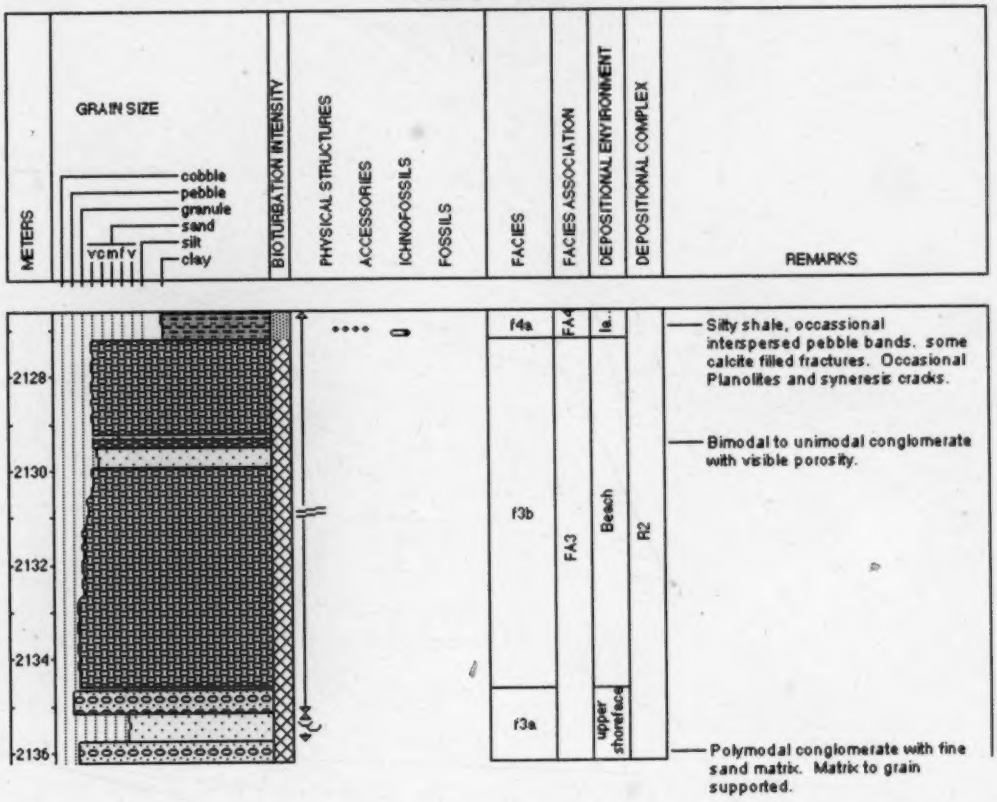
**Canhunter et al Wapiti**

**05-20-067-09w6**

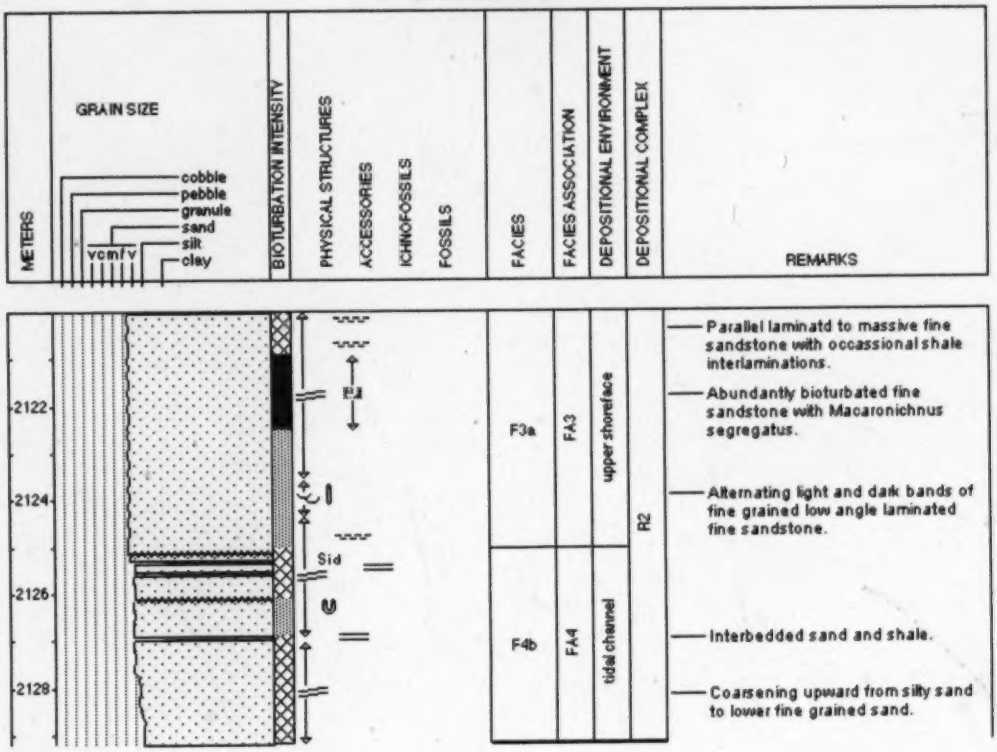


**Imperial et al. Wapiti**

**10-21-067-09w6**

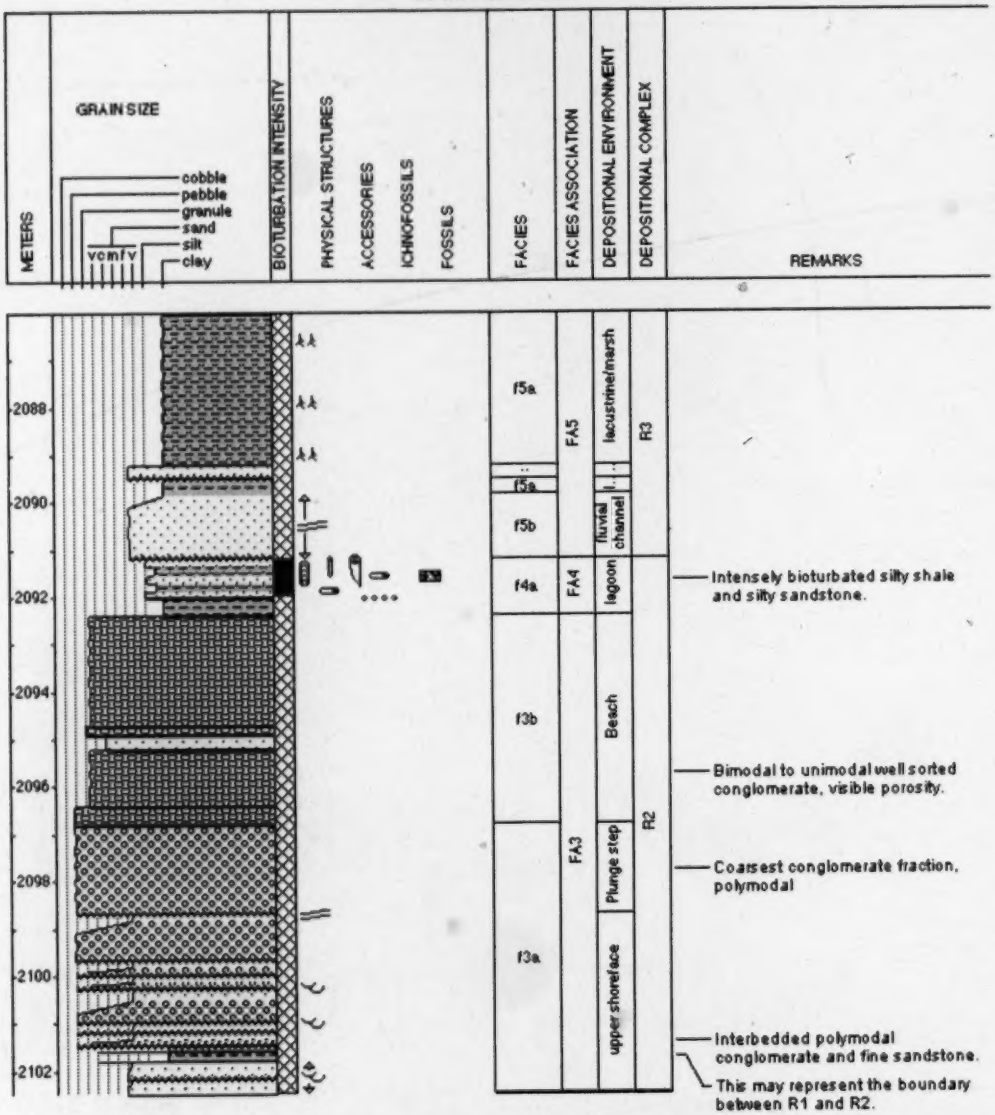


**Amoco et al. Wapiti**
**12-23-067-09w6**



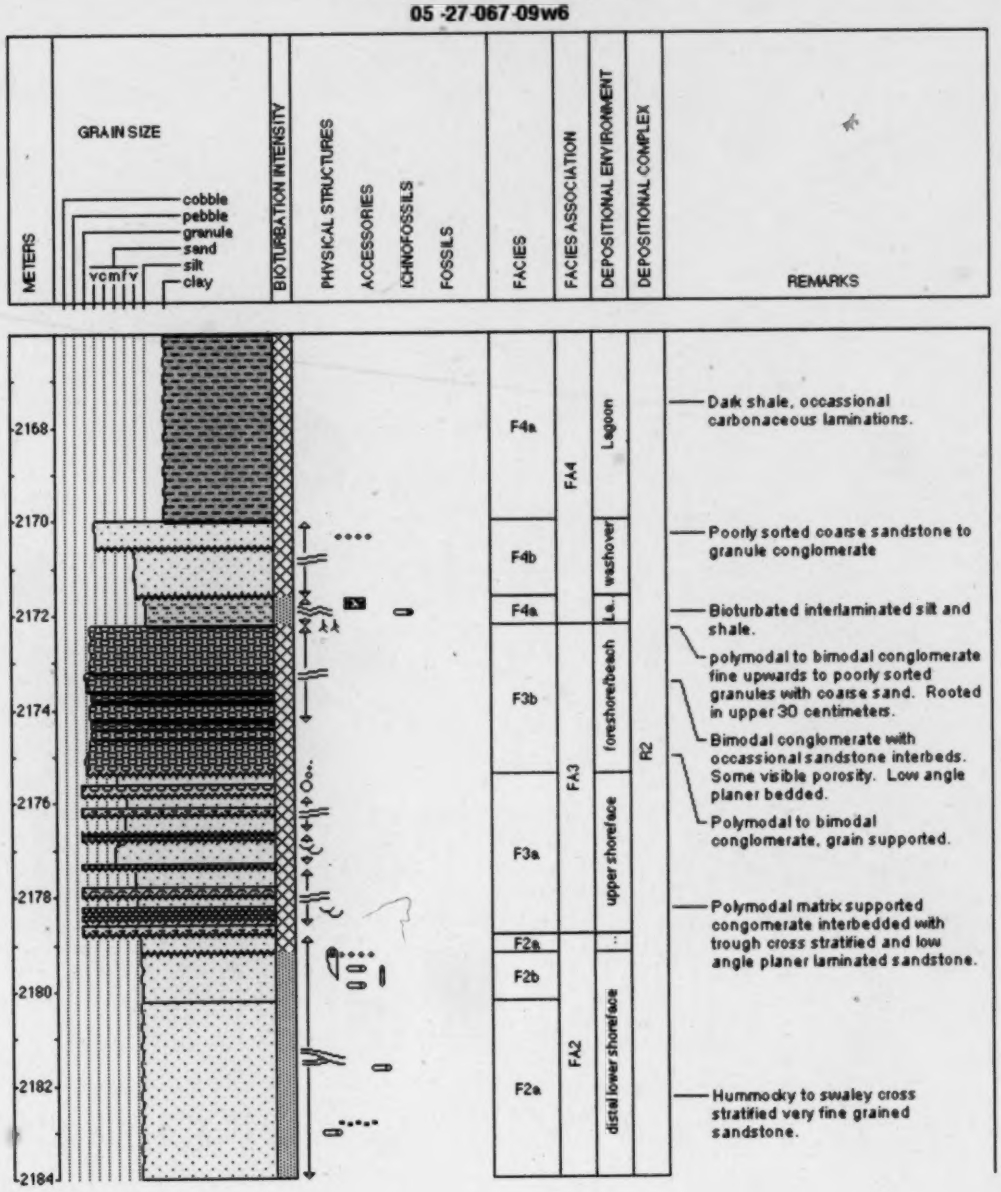
**canhunter et. al. wapiti**

**06-25-067-09w6**



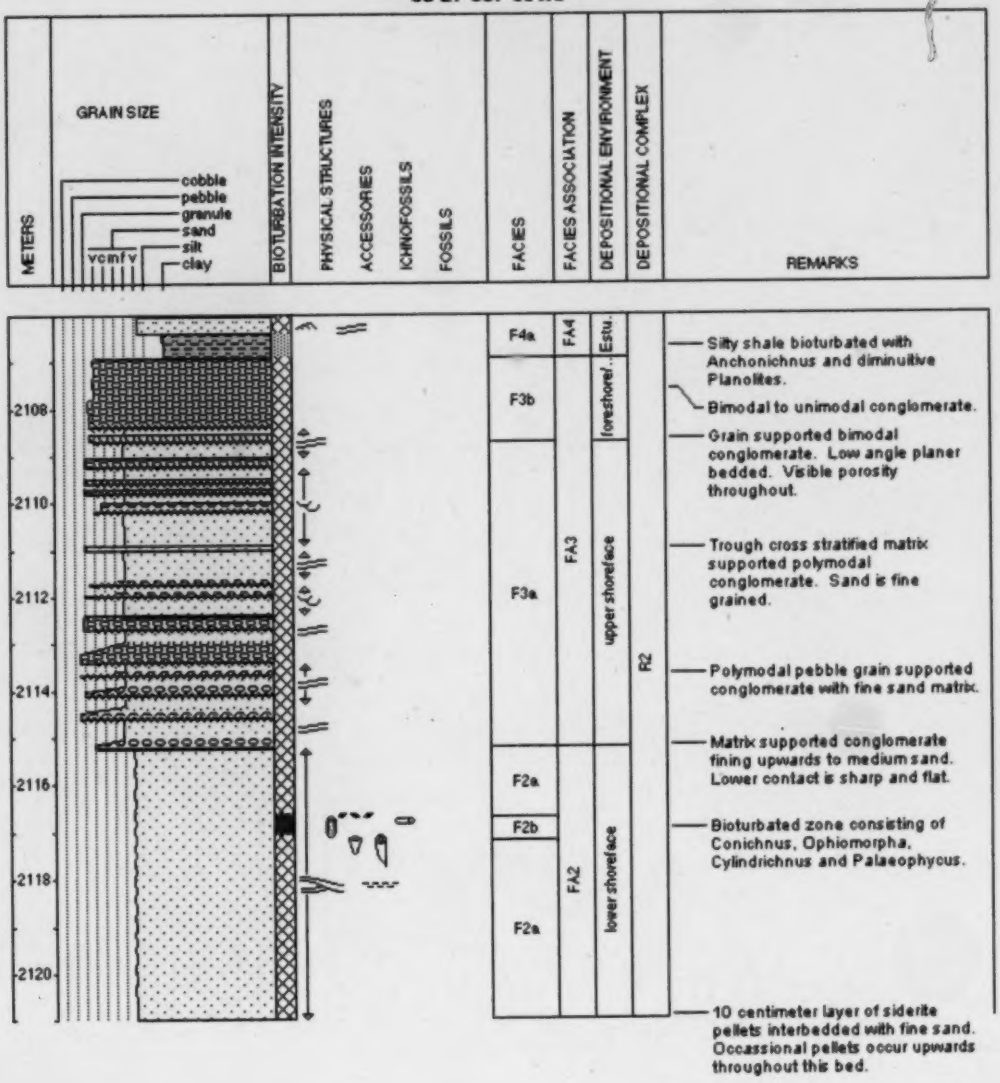
**canhunter et. al wapiti**

**05 -27-067-09w6**



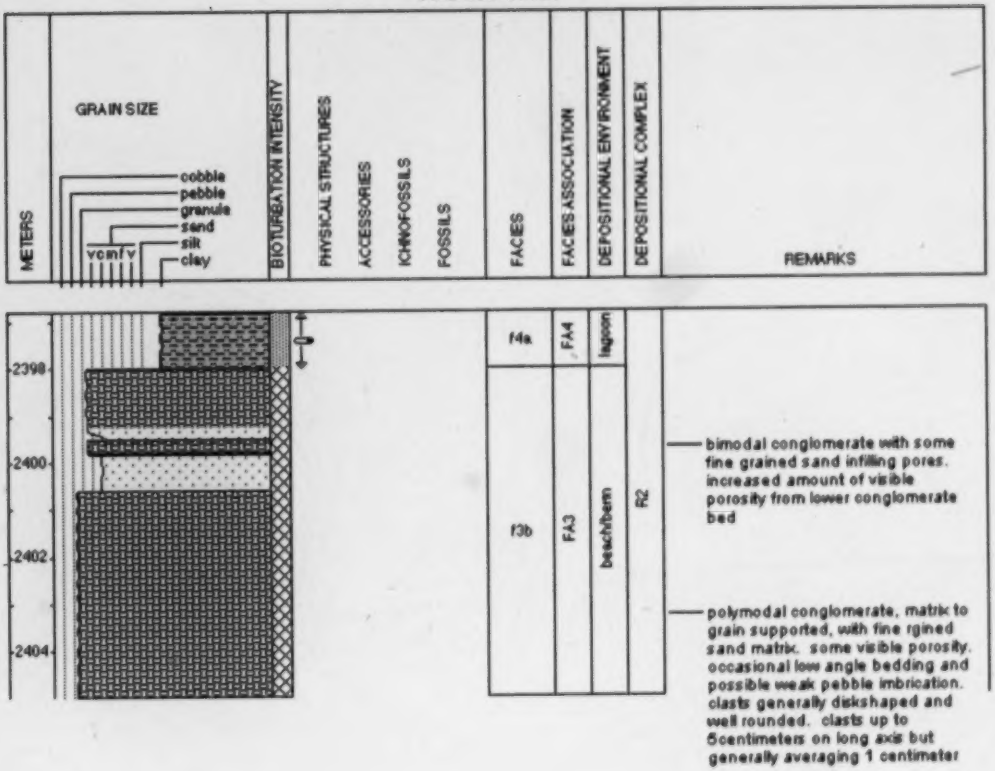
**Amoco et al Stone Creek**

**06-27-067-09w6**

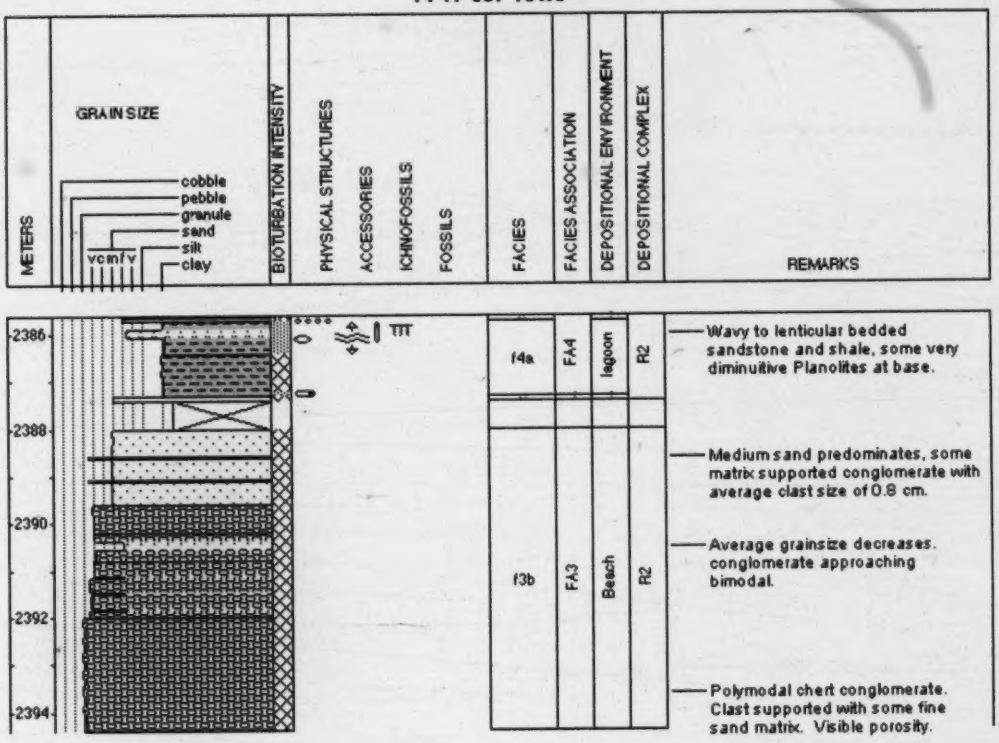


**Amoco et al Wapiti**

**14-8-067-11w6**

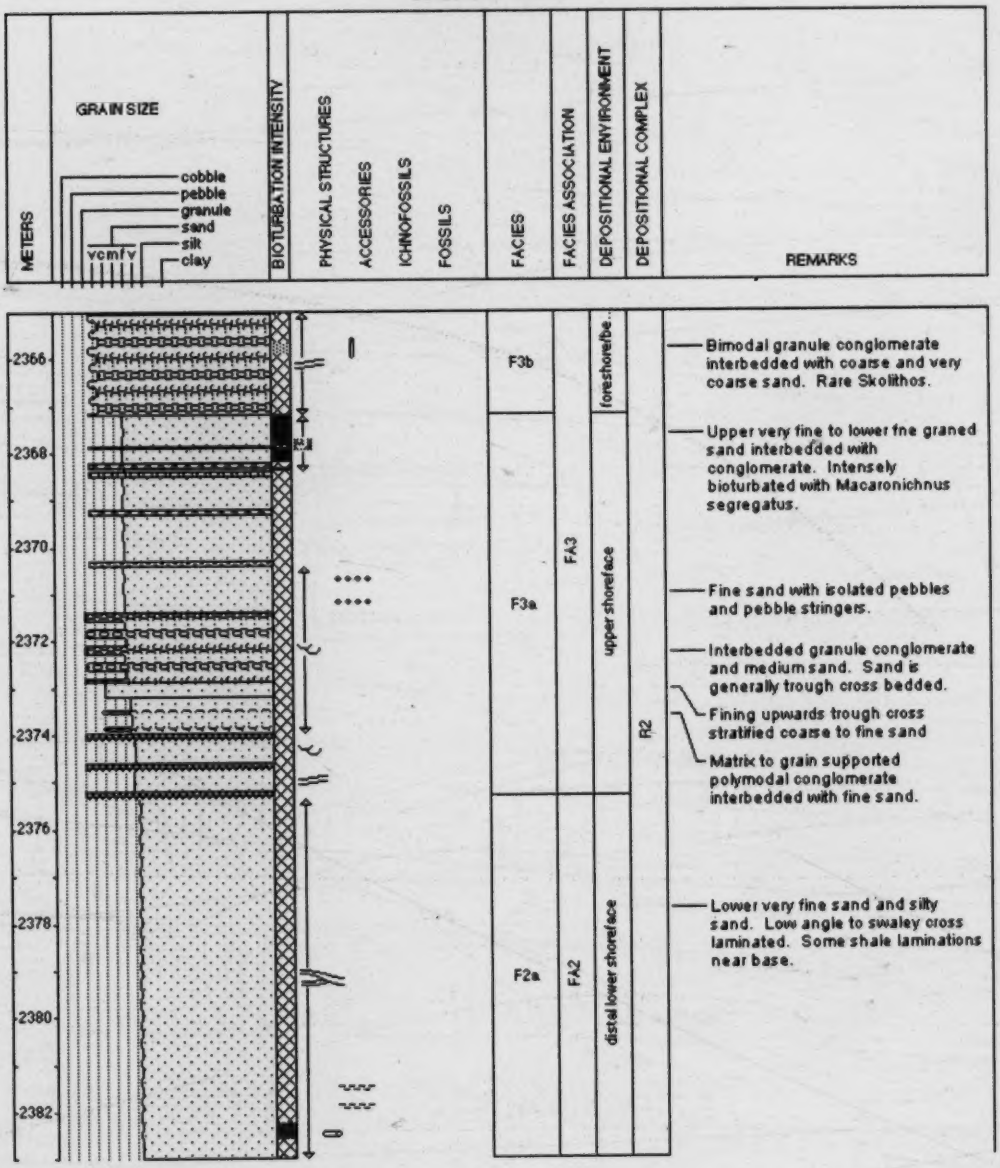


**Amoco et. al Wapiti**
**14-17-067-10w6**



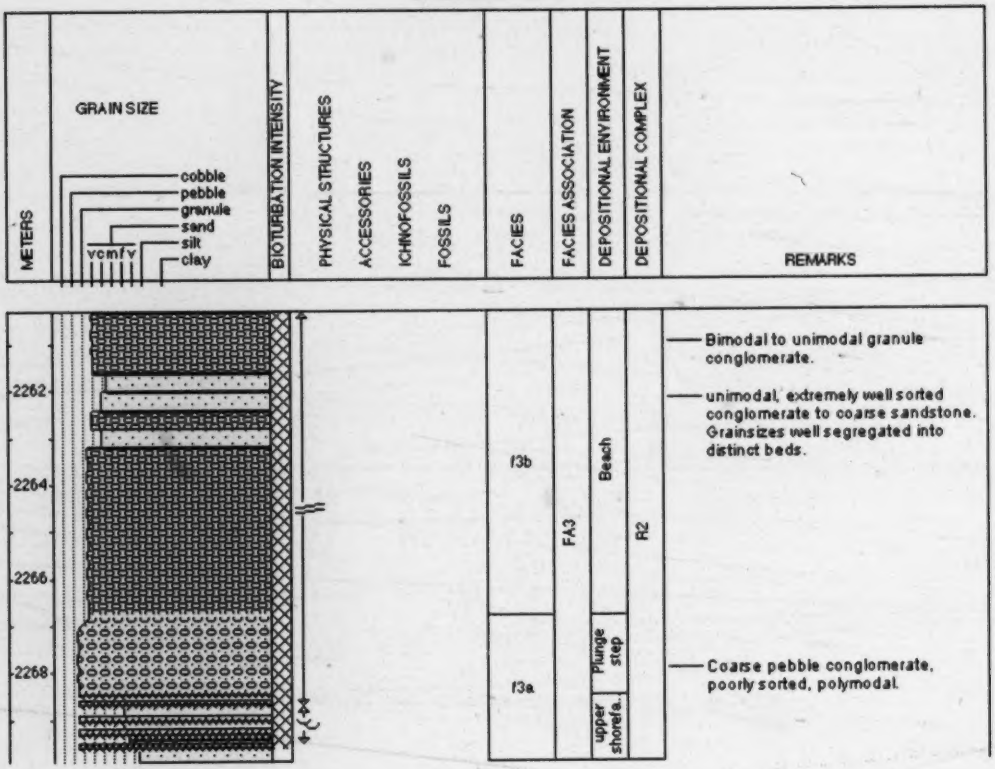
## Canhunter et al. Grayling

**06-21-067-10w6**

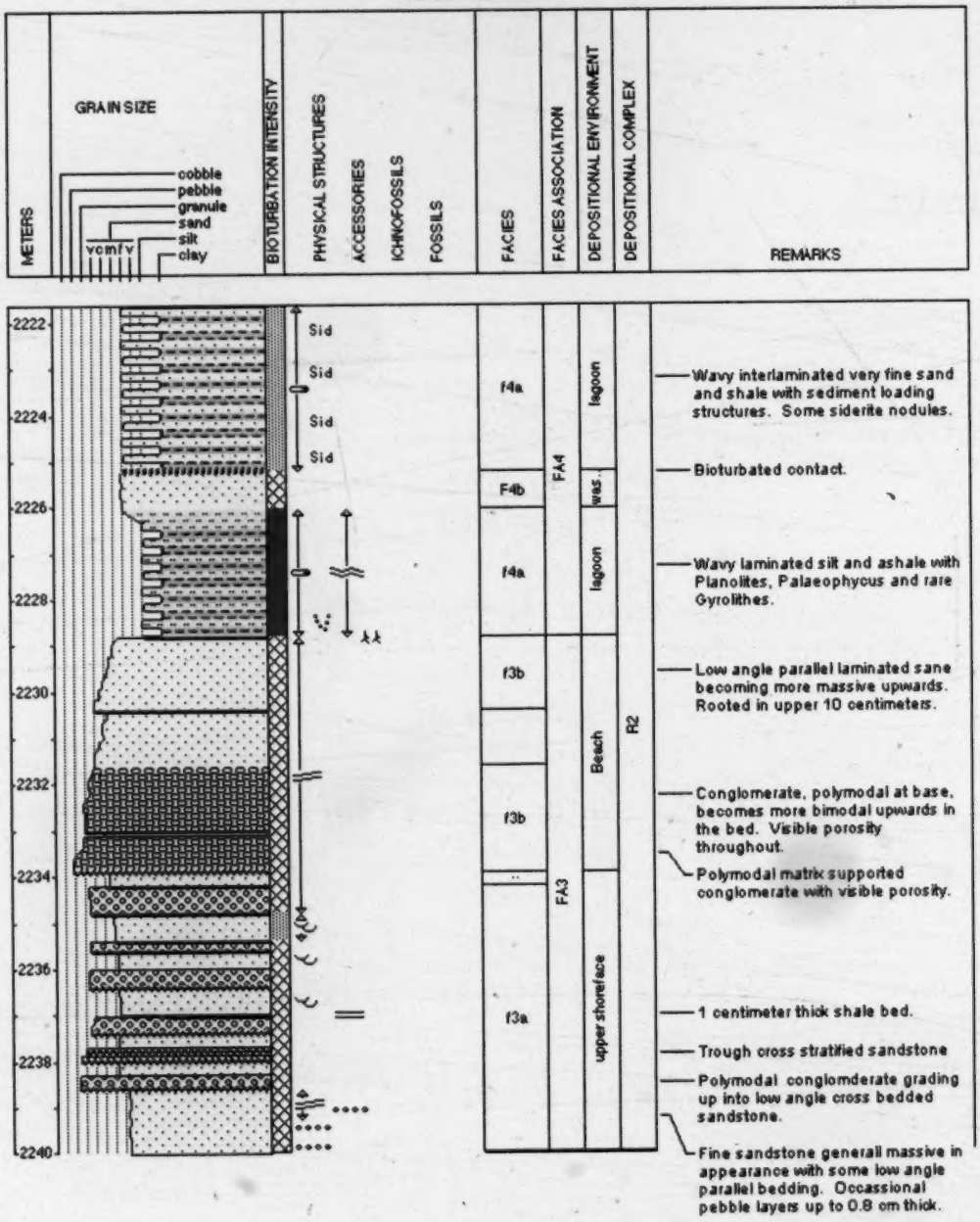


**Amoco et. al. Wapiti**

**07-23-067-10w6**

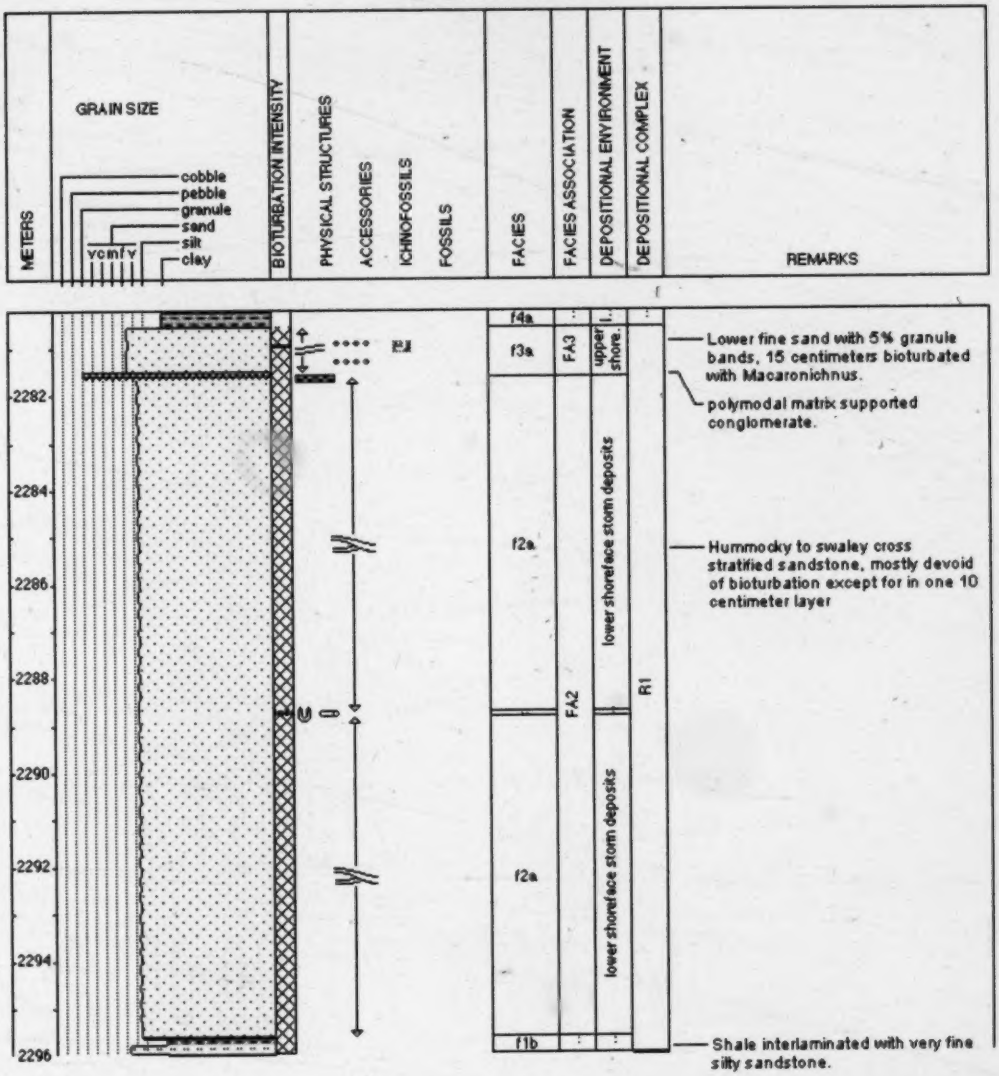


**Imperial et al. Wapiti**
**15-23-067-10w6**



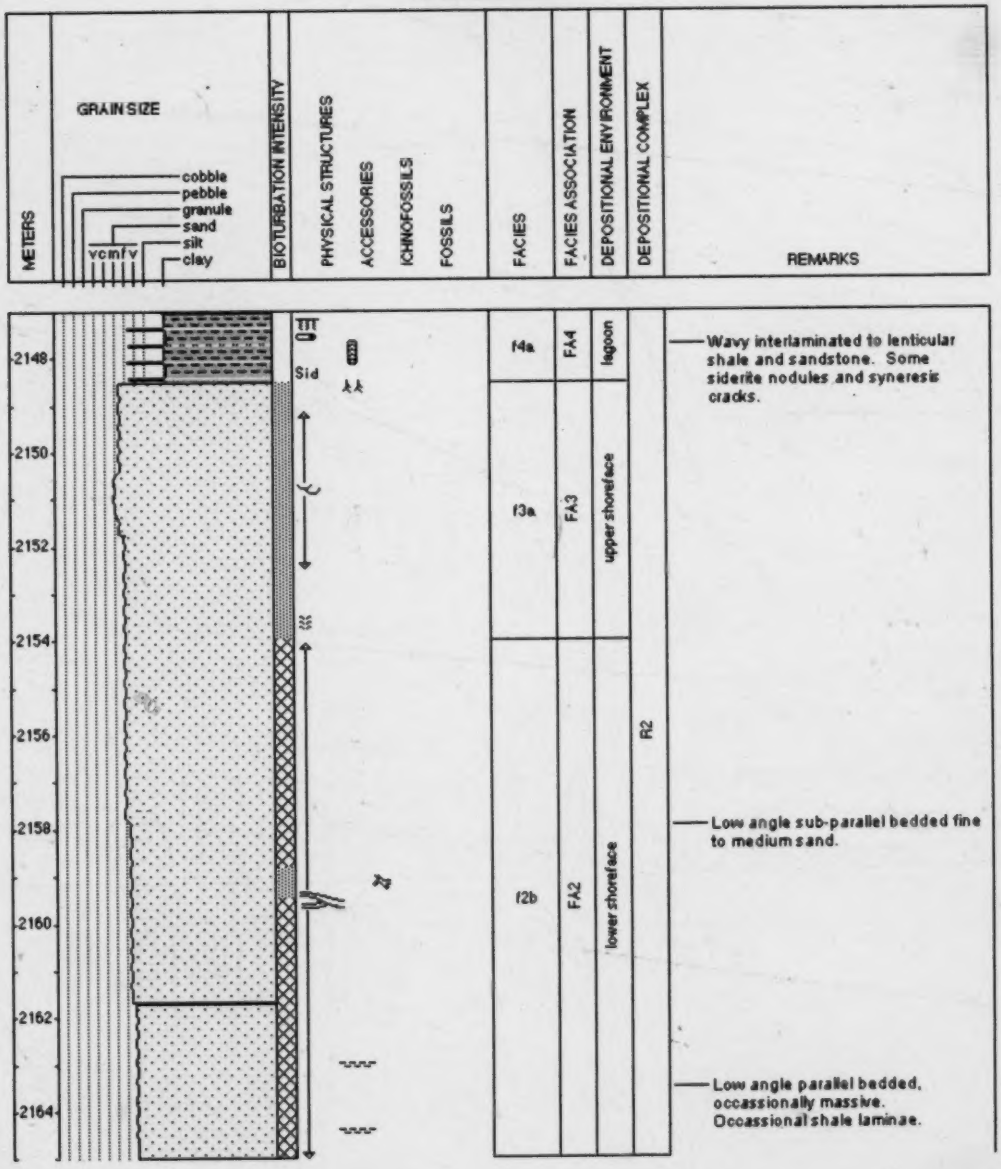
**Amoco et al. Grayling**

**07-27-067-10w6**

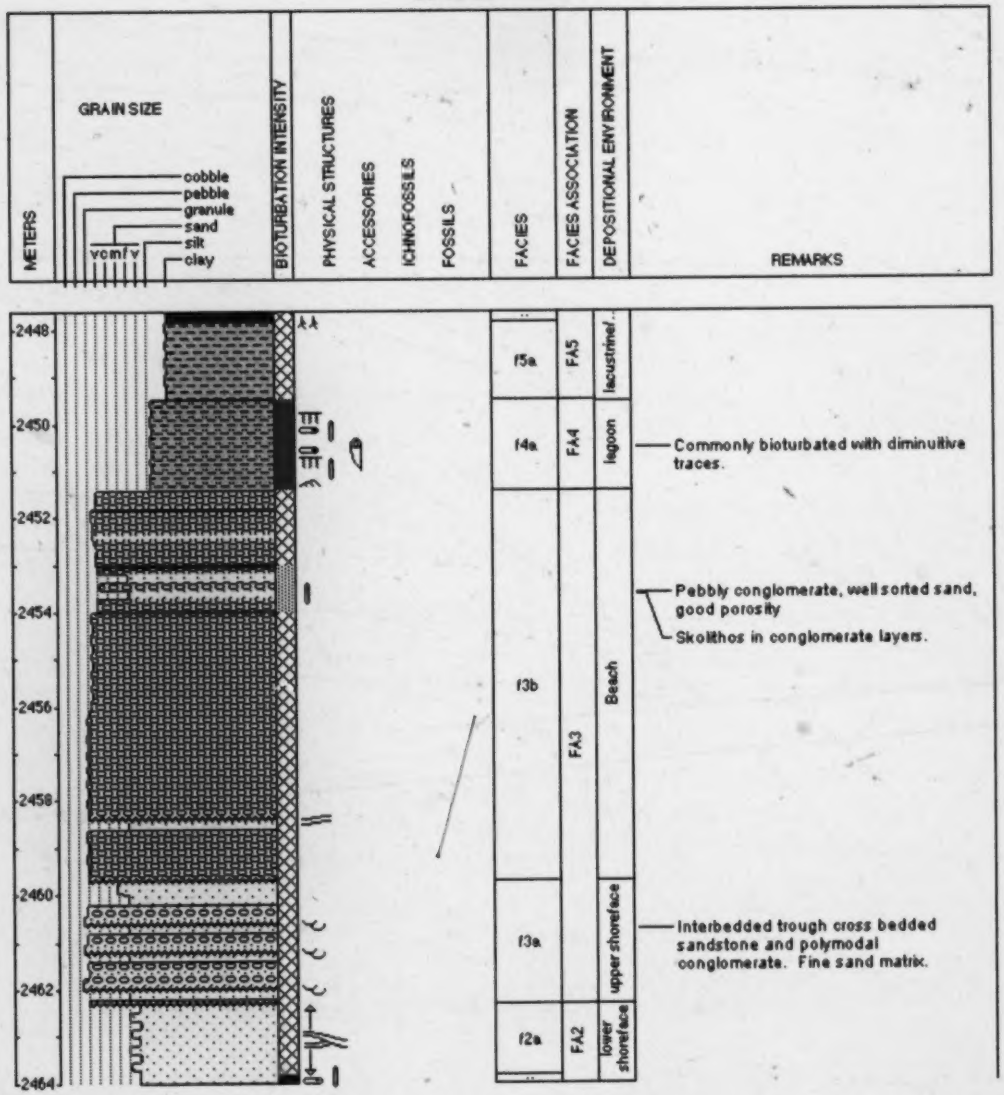


**Imperial et al. Wapiti**

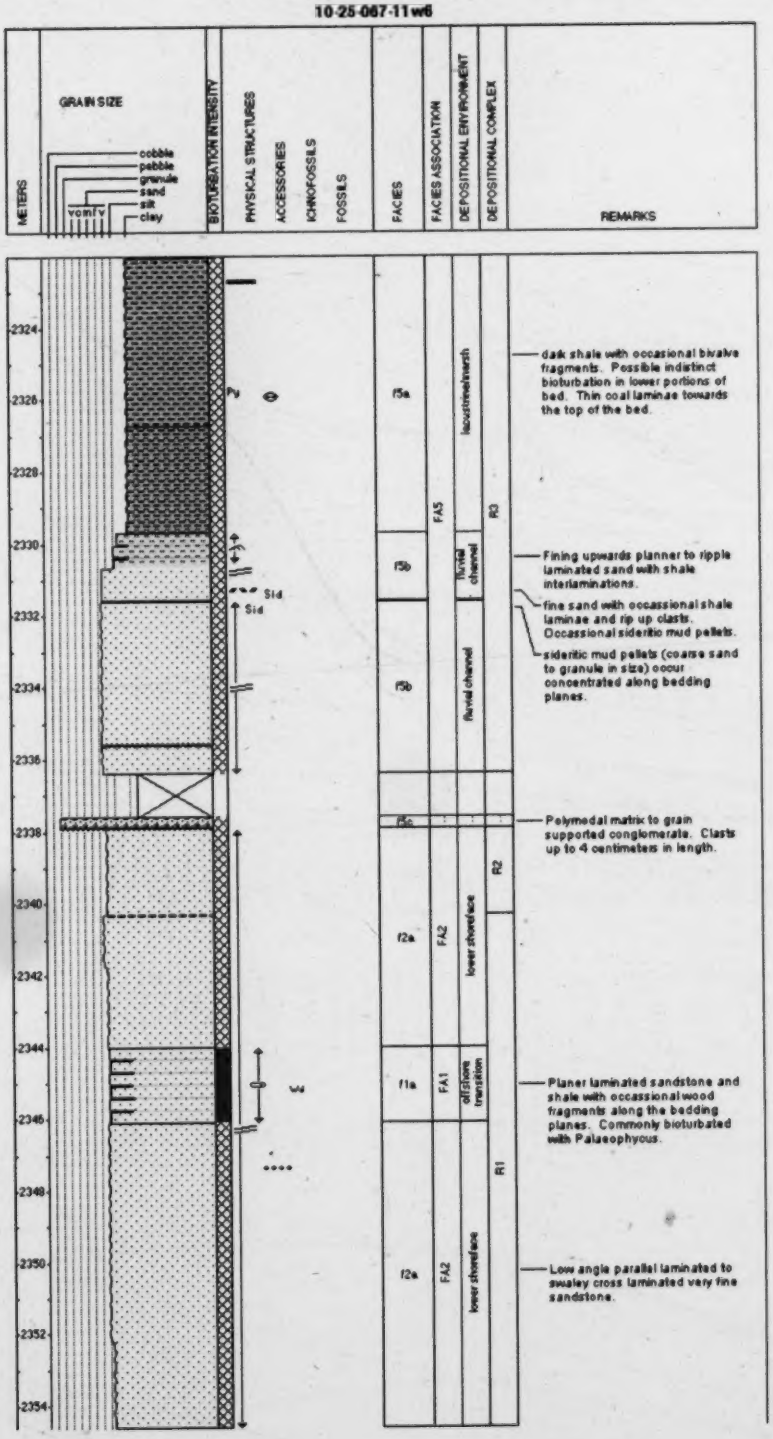
**07-35-067-10w6**



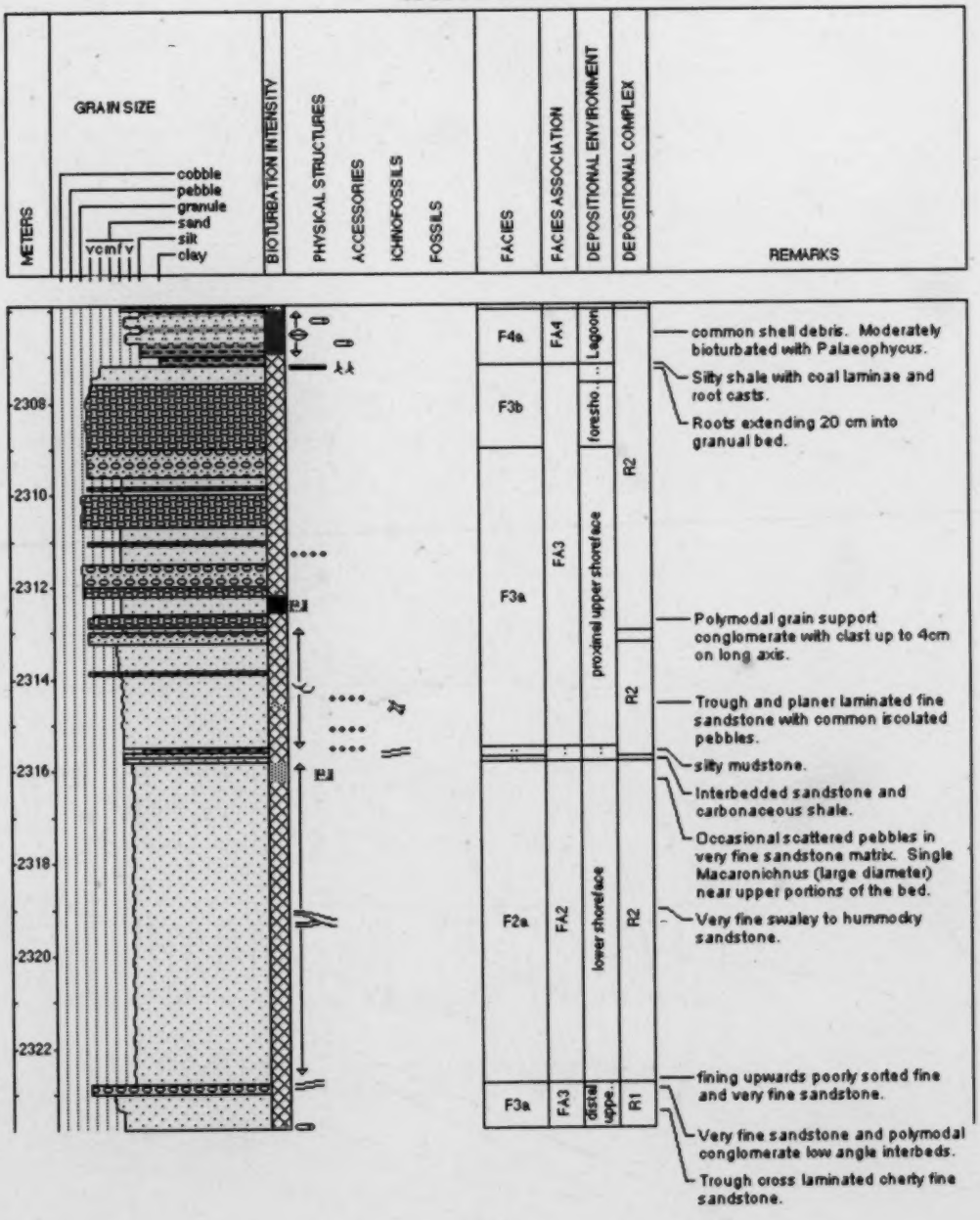
**Imperial Wapiti**
**08-15-067-11w6**



**Canhunter et al. Elmworth**
**10-25-067-11w6**

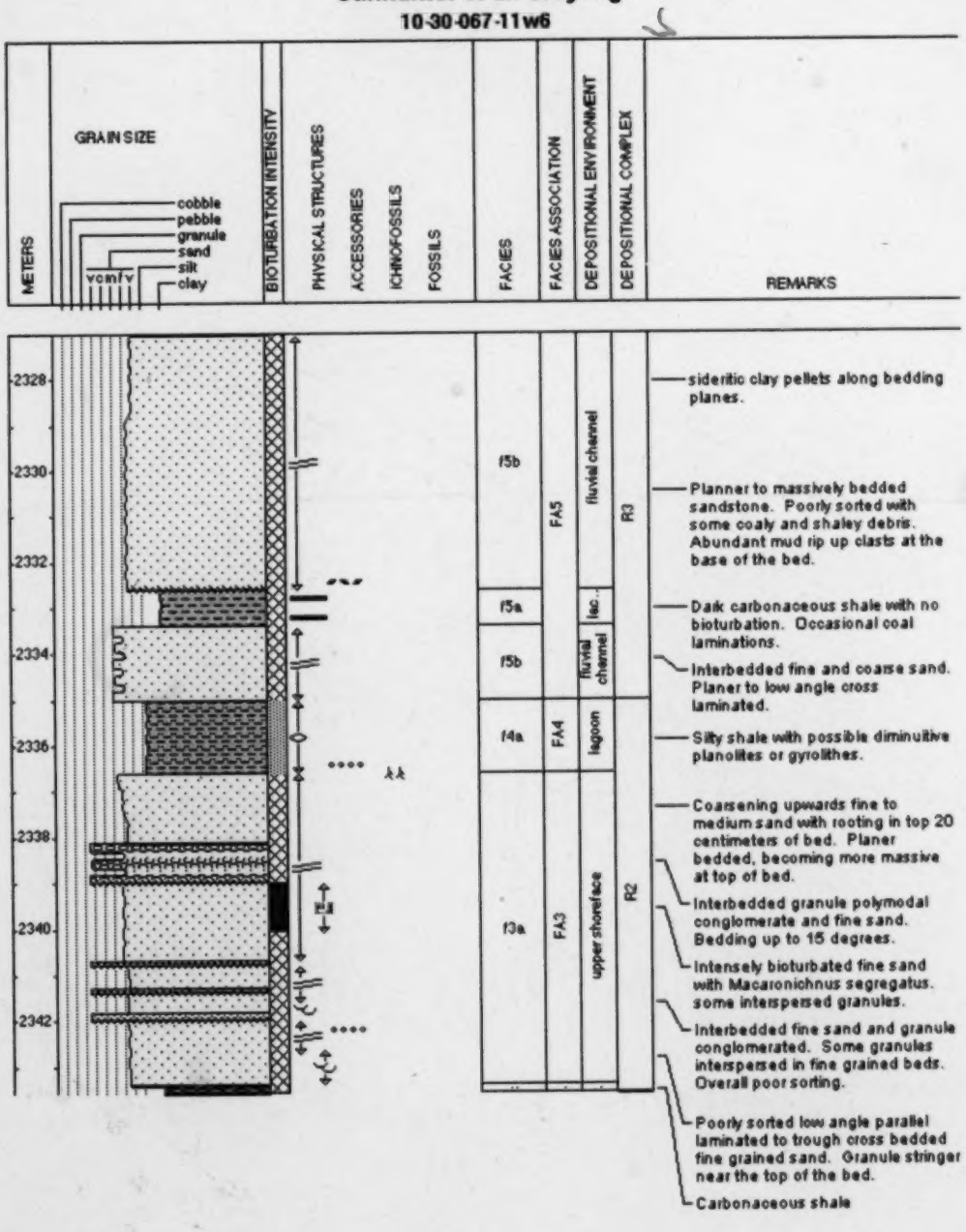


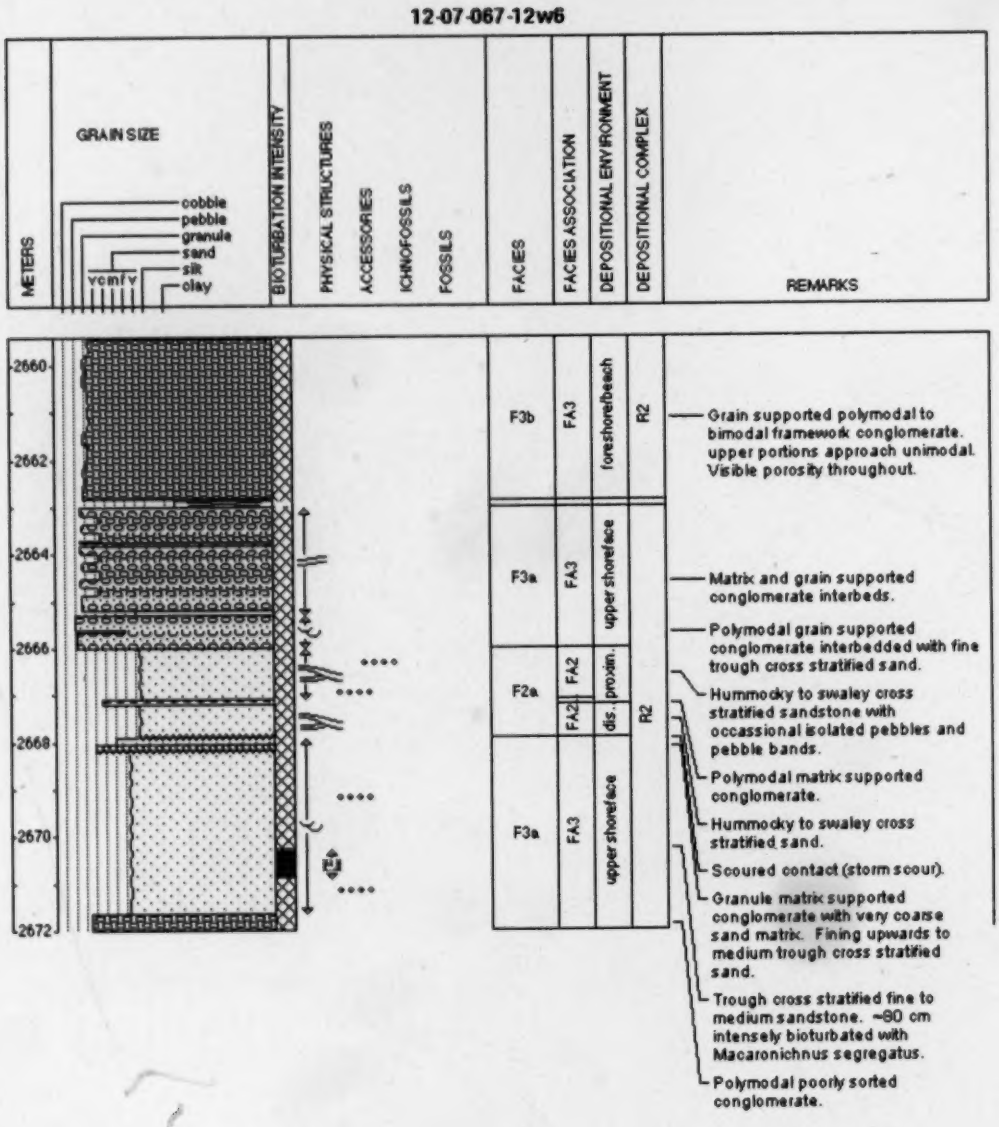
08-26-067-11w6



**Canhunter et al. Grayling**

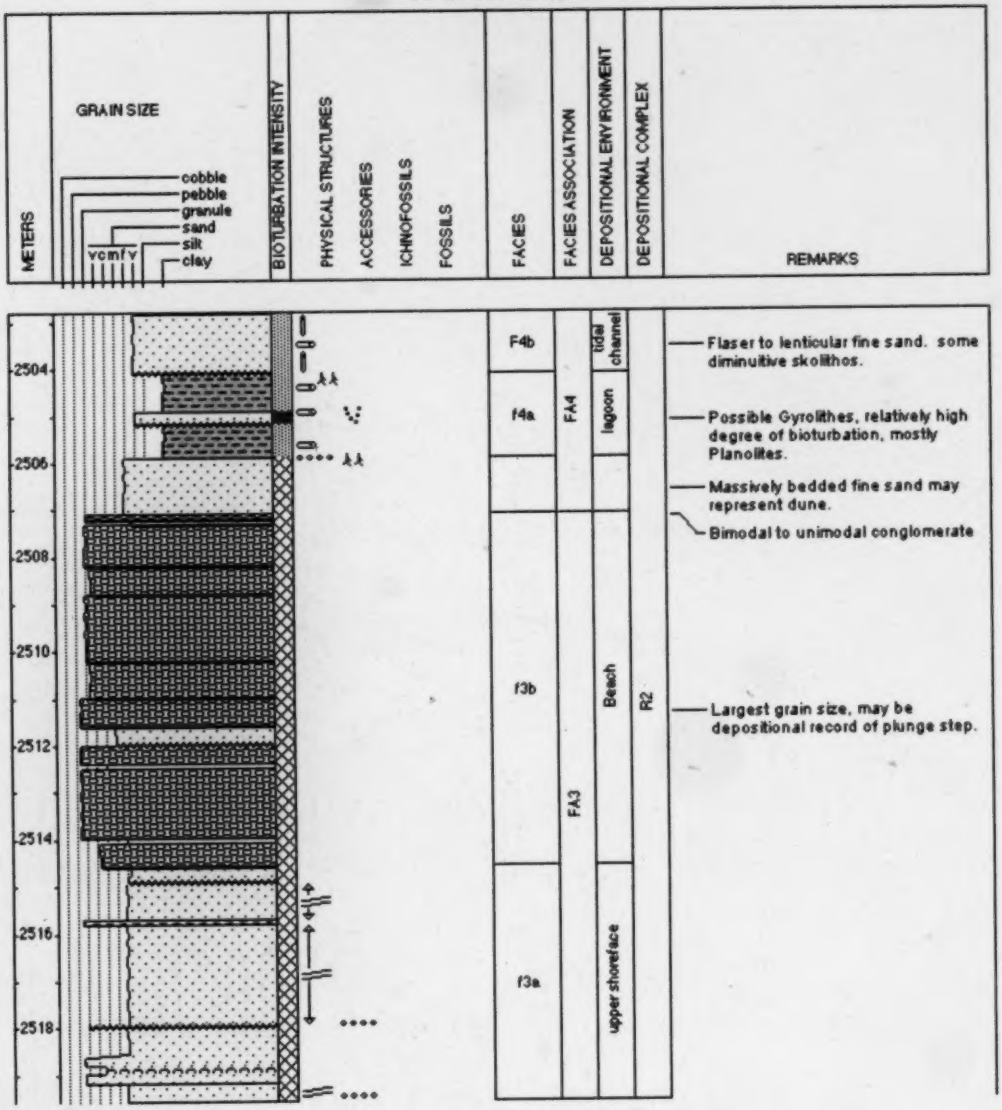
**10-30-067-11w6**




12-07-067-12w6
METERS
GRAIN SIZE
cobble
pebble
granule
sand
silt
clay
vc m f v
BIOTURBATION INTENSITY
PHYSICAL STRUCTURES
ACCESSORIES
ICHNOFOSSILS
FOSSILS
FACIES
FACIES ASSOCIATION
DEPOSITIONAL ENVIRONMENT
DEPOSITIONAL COMPLEX
REMARKS
2660
2662
2664
2666
2668
2670
2672
F3b
FA3
foreshore/beach
R2
F3a
FA3
upper shoreface
F2a
FA2
proxin.
FA2
dis.
F3a
FA3
upper shoreface
R2
Grain supported polymodal to bimodal framework conglomerate. upper portions approach unimodal. Visible porosity throughout.
Matrix and grain supported conglomerate interbeds.
Polymodal grain supported conglomerate interbedded with fine trough cross stratified sand.
Hummocky to swaley cross stratified sandstone with occassional isolated pebbles and pebble bands.
Polymodal matrix supported conglomerate.
Hummocky to swaley cross stratified sand.
Scoured contact (storm scour).
Granule matrix supported conglomerate with very coarse sand matrix. Fining upwards to medium trough cross stratified sand.
Trough cross stratified fine to medium sandstone. ~80 cm intensely bioturbated with Macaronichnus segregatus.
Polymodal poorly sorted conglomerate.

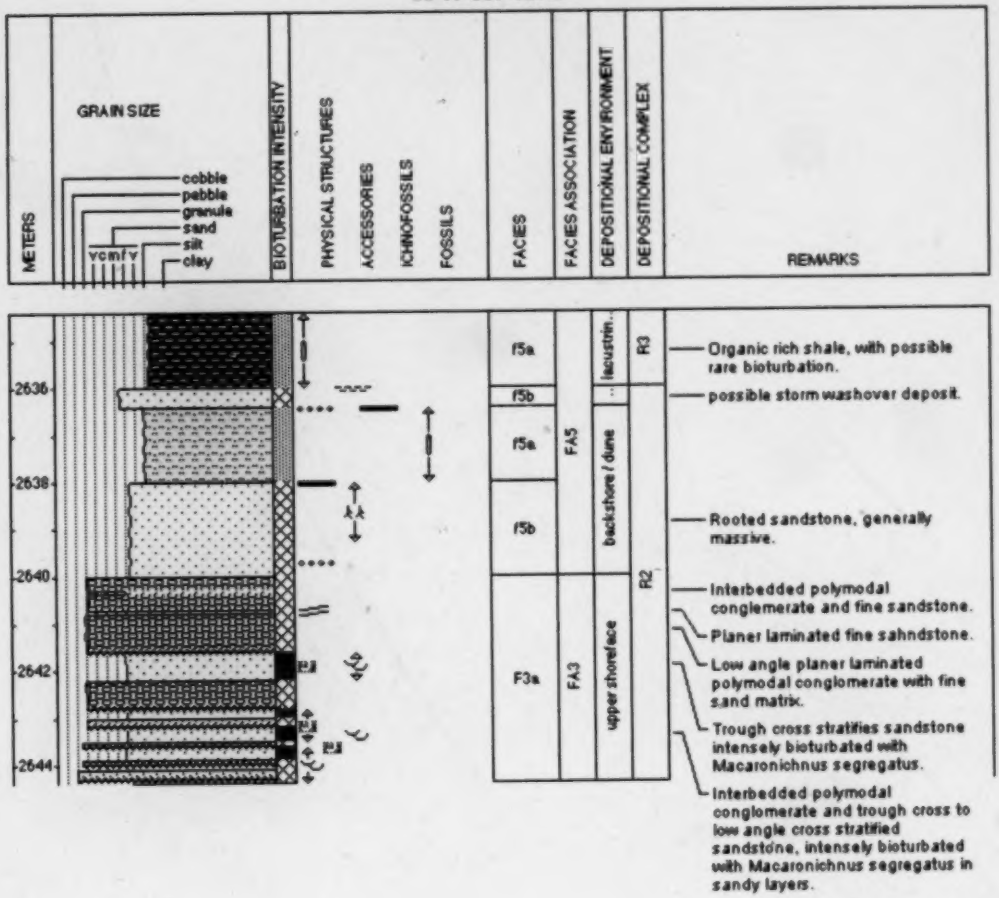
**Amoco et. al Wapiti**

**15 -09-067-12w6**

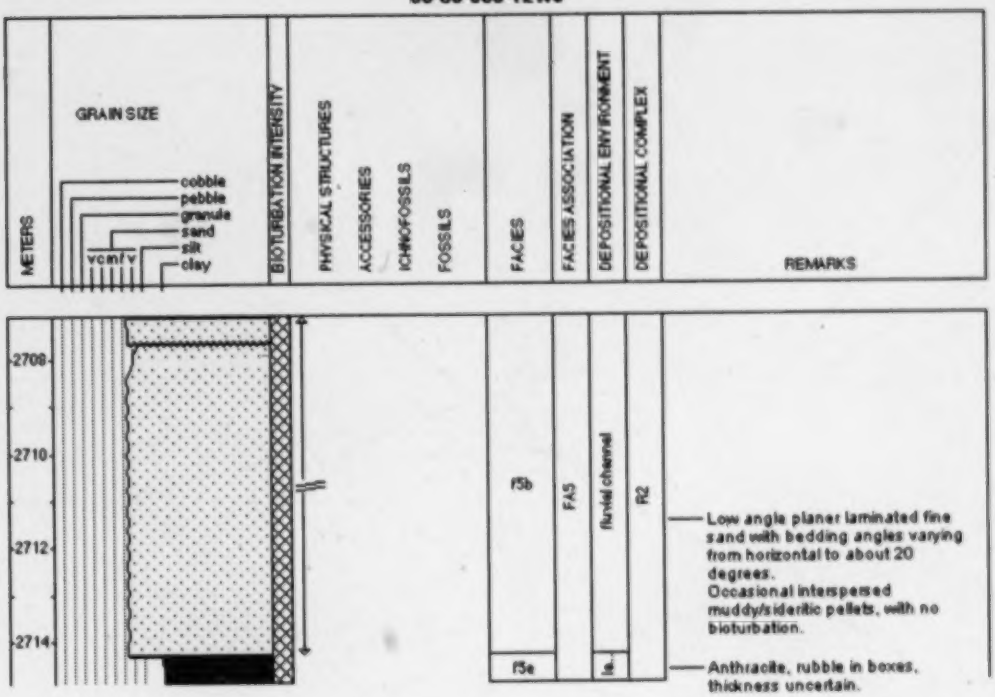


**Canhunter et al. Wapiti**

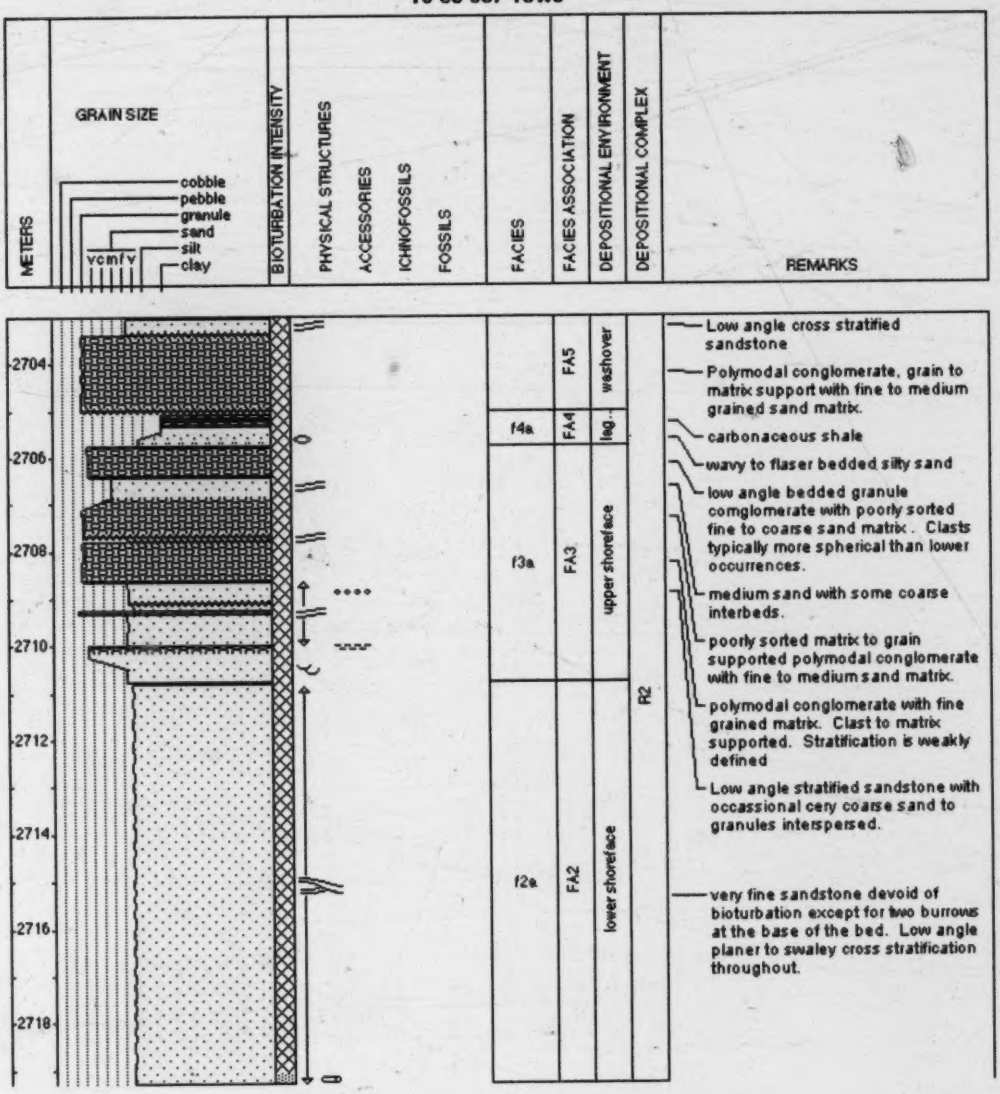
**03-17-067-12w6**



**Shell et al. Noseck**
**06-36-065-12w6**

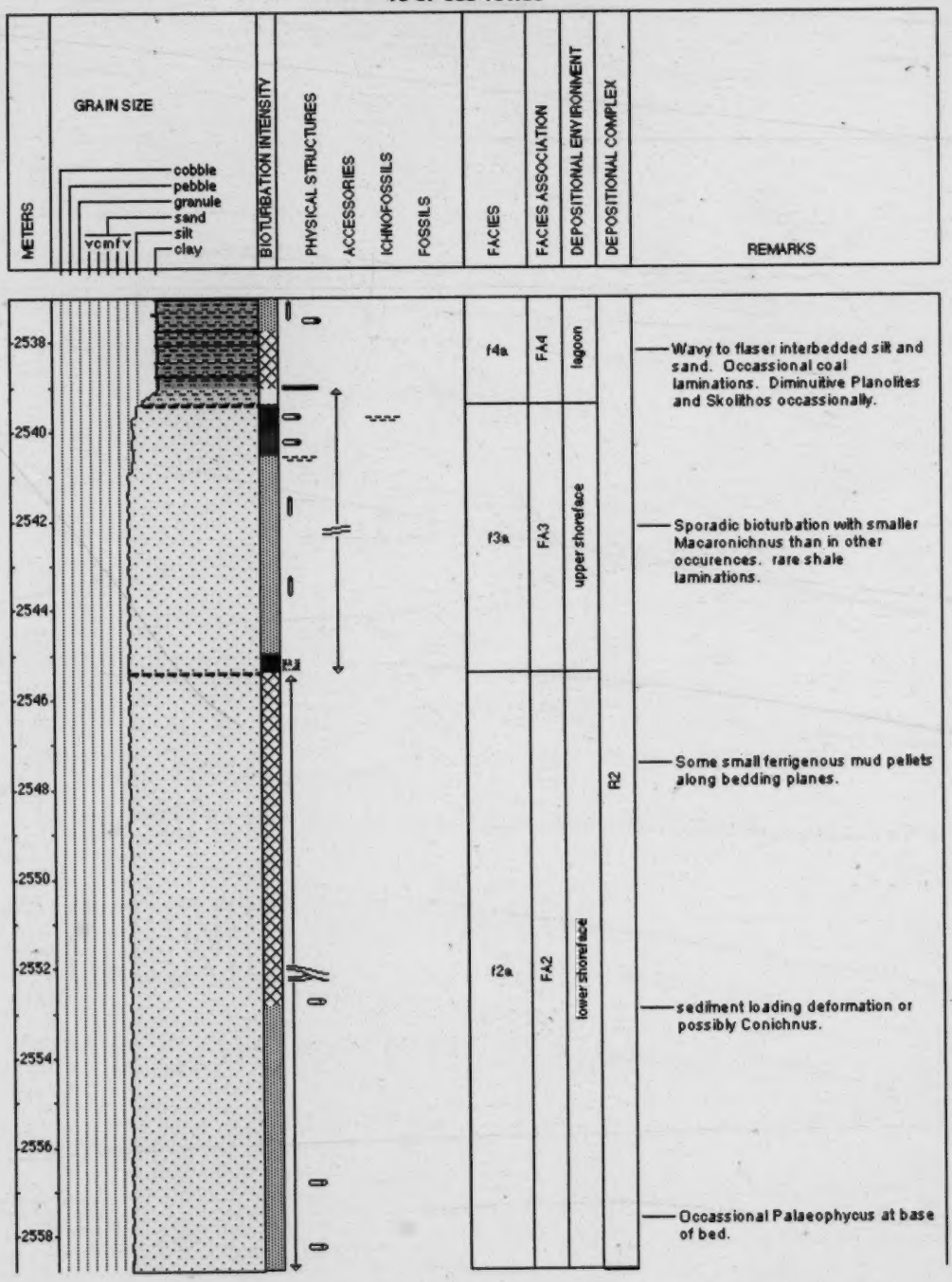


10-05-067-13w6



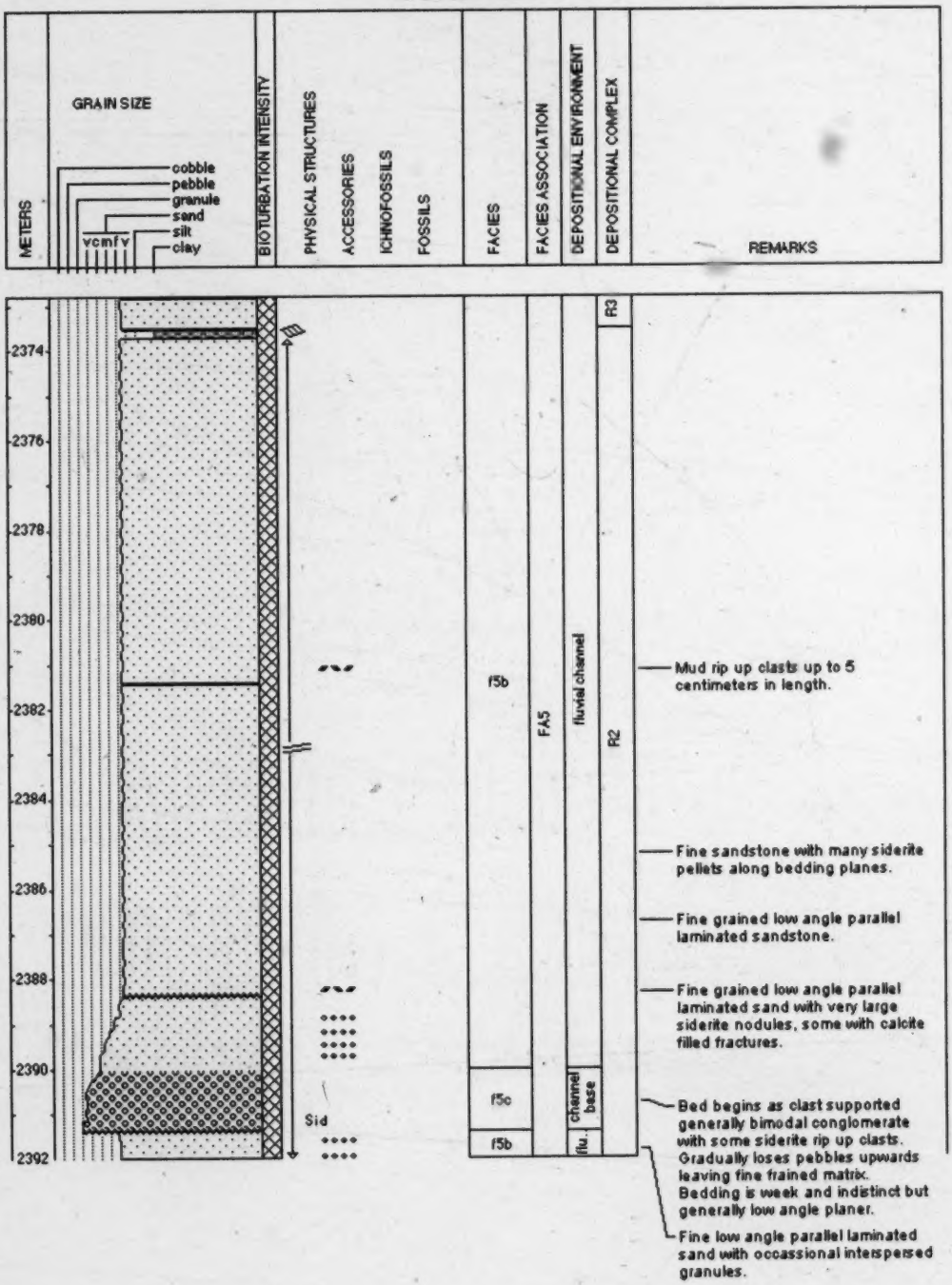
**Esso Canhunter Sylvester**

**10-07-068-13w06**

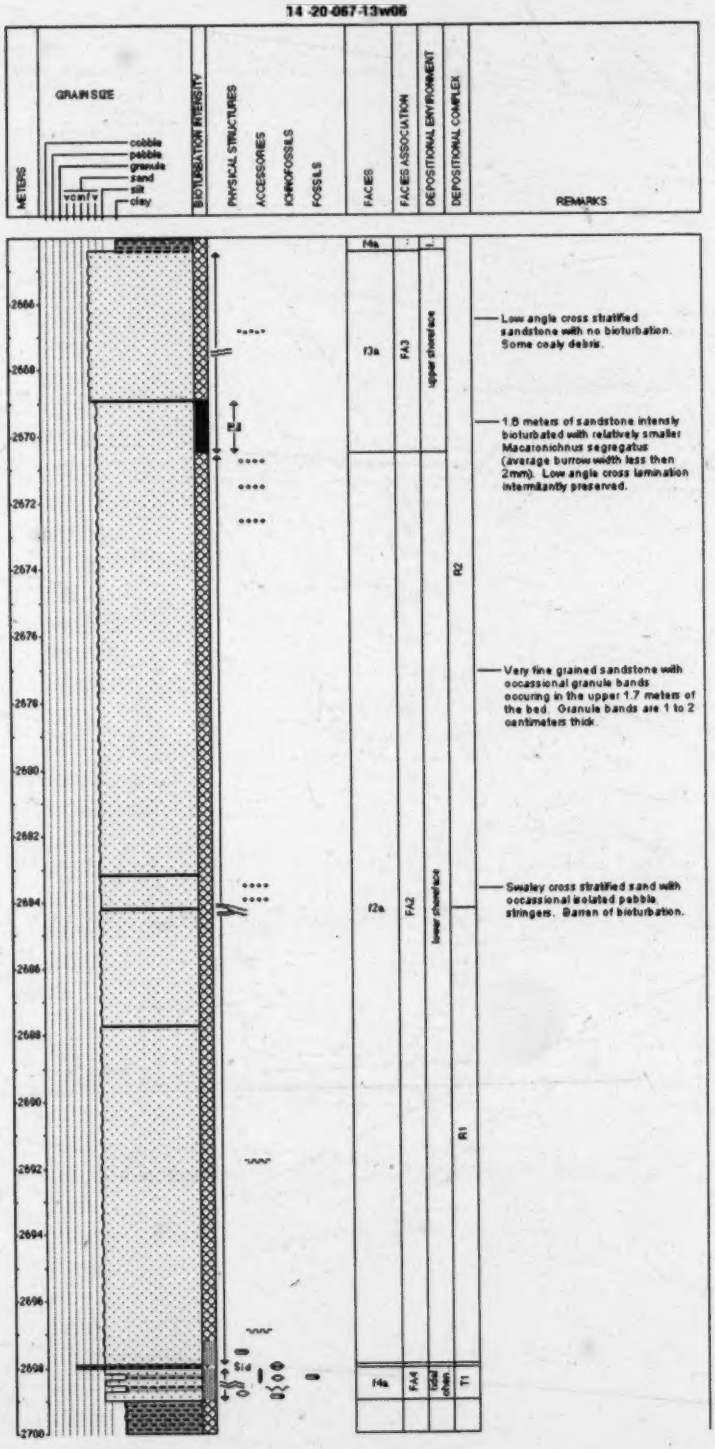


**Canhunter Wapiti**

**10-08-067-13w6**

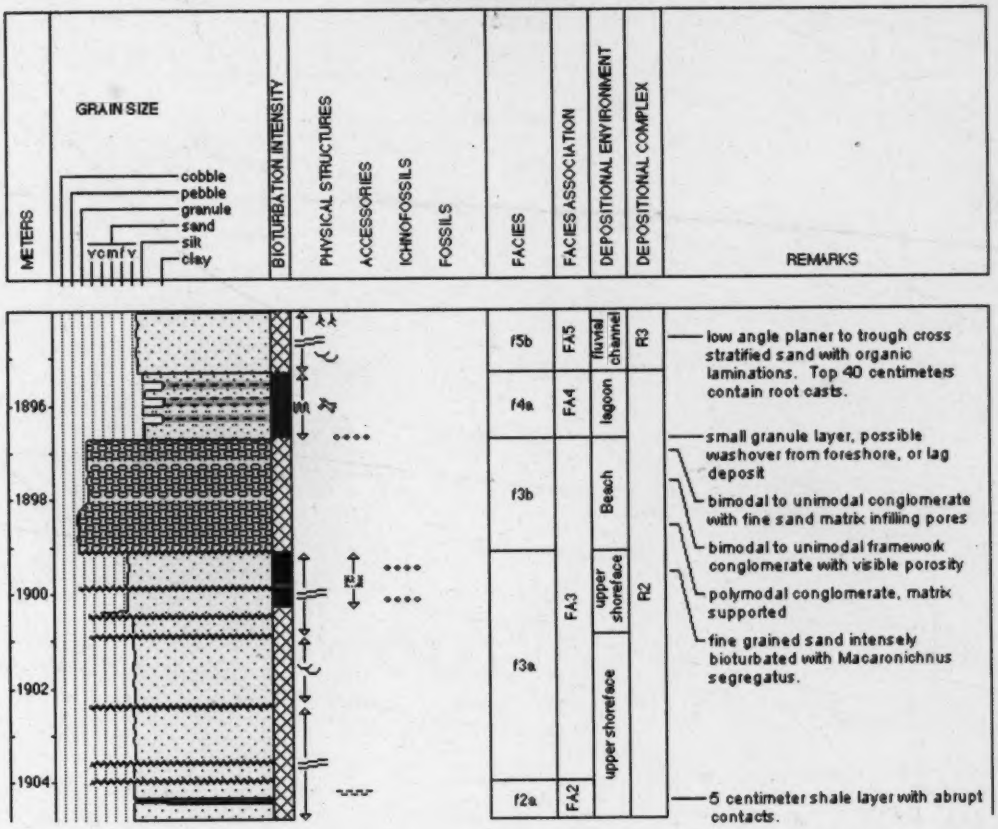


14-20-067-13w06



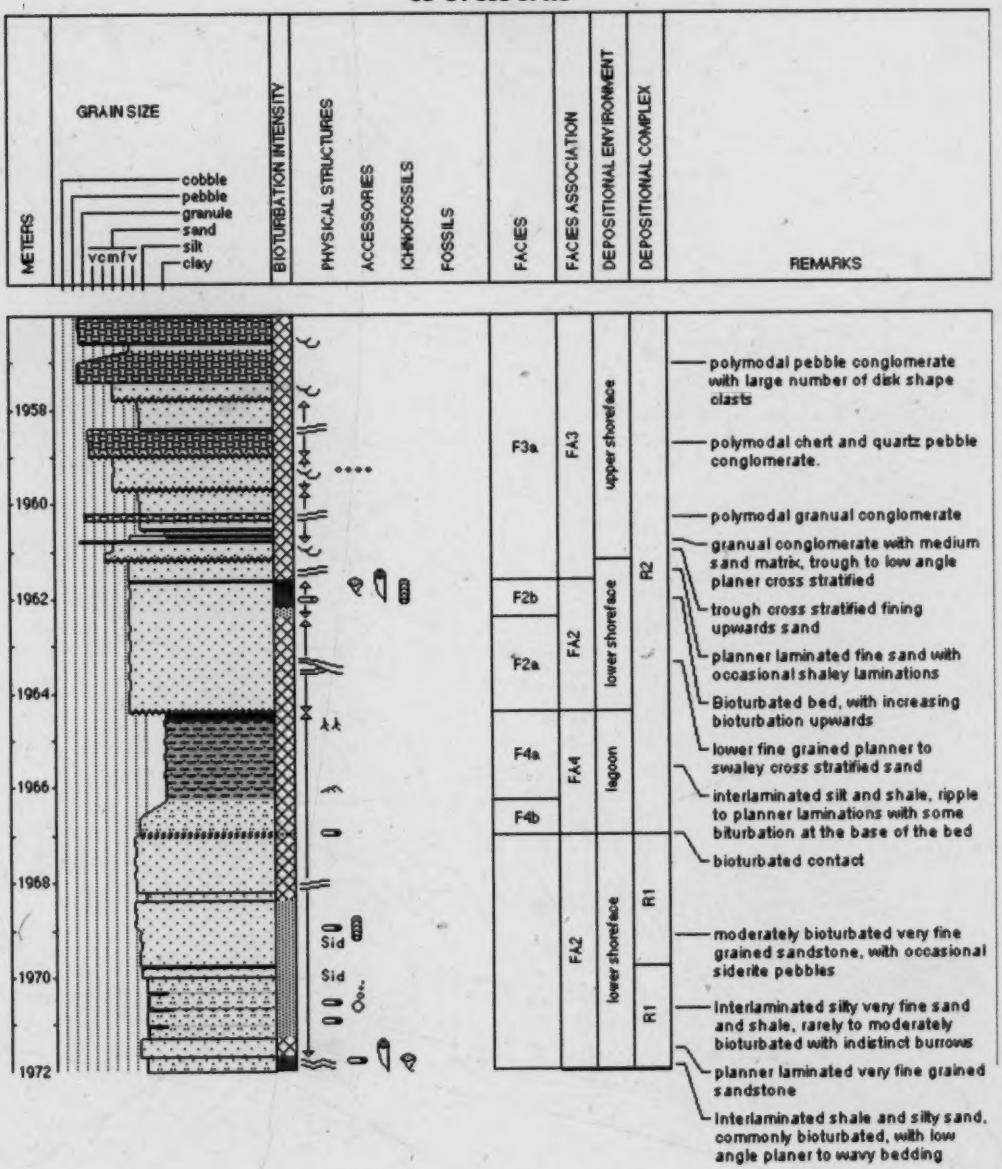
**Amoco et al. Wapiti**

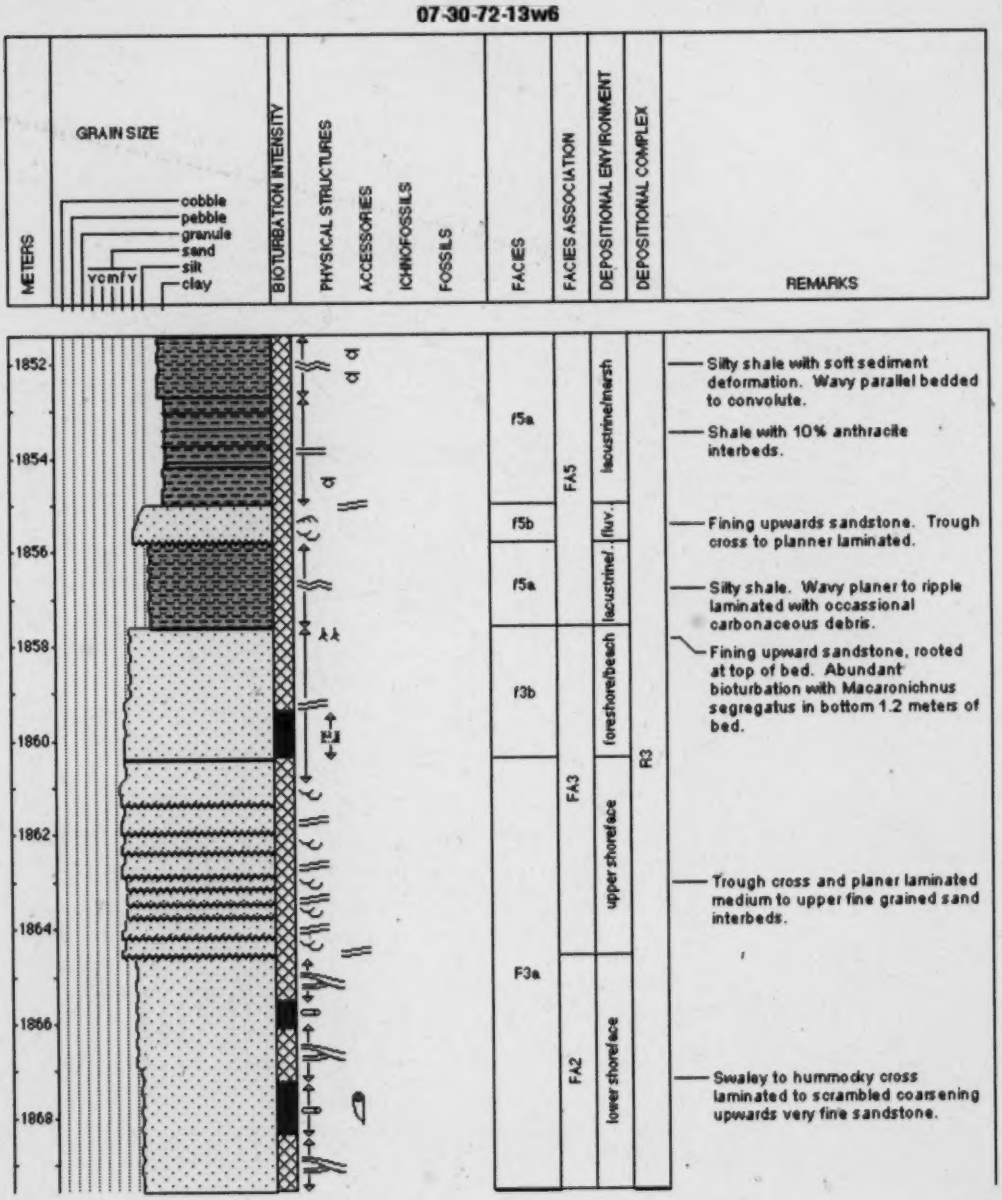
**13-02-068-07w6**



**Enron Wapiti**

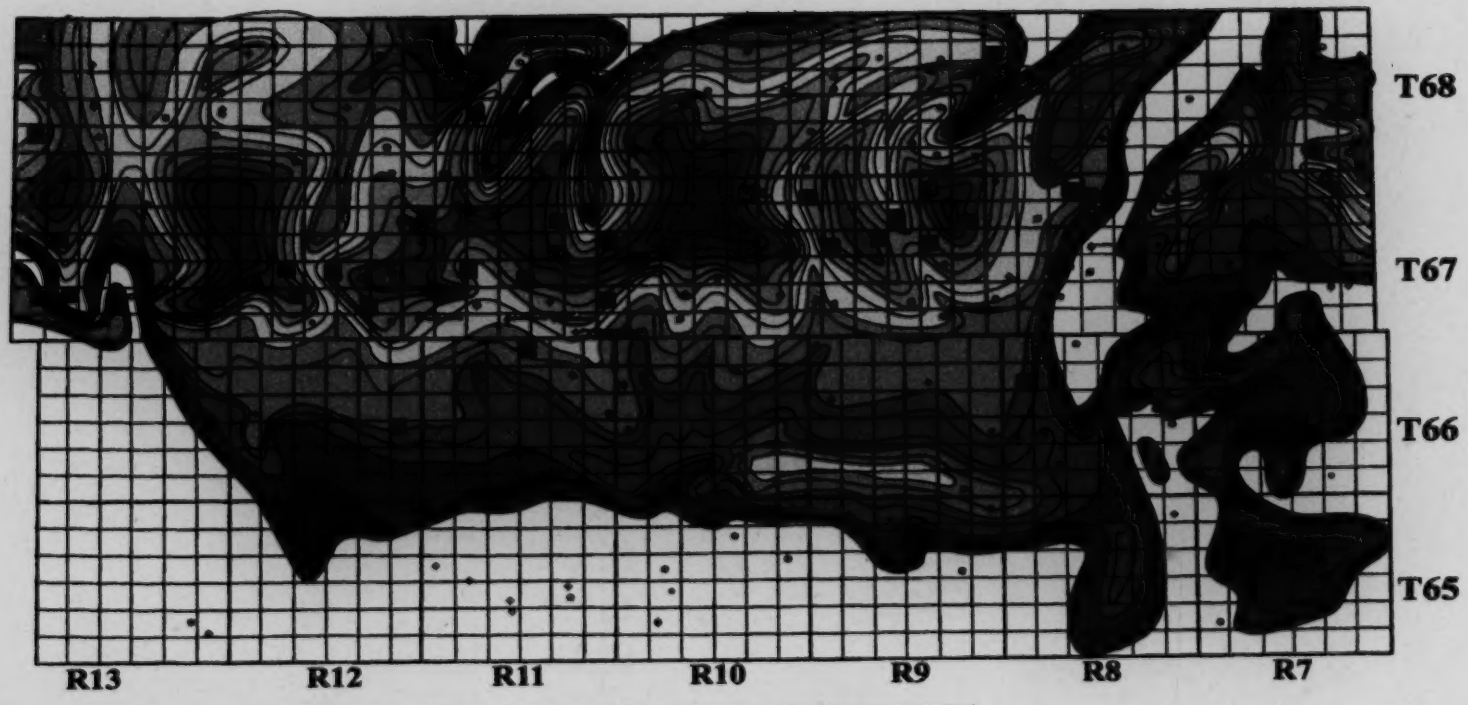
**06-04-068-07w6**




07-30-72-13w6
METERS
GRAIN SIZE
cobble
pebble
granule
sand
silt
clay
vc m f v
BIOTURBATION INTENSITY
PHYSICAL STRUCTURES
ACCESSORIES
ICHNOFOSSILS
FOSSILS
FACIES
FACIES ASSOCIATION
DEPOSITIONAL ENVIRONMENT
DEPOSITIONAL COMPLEX
REMARKS
1852
1854
1856
1858
1860
1862
1864
1866
1868
f5a
f5b
f5a
f3b
F3a
FA5
FA3
FA2
lacustrine/marsh
fluv.
lacustrine/
foreshore/beach
upper shoreface
lower shoreface
R3
Silty shale with soft sediment deformation. Wavy parallel bedded to convolute.
Shale with 10% anthracite interbeds.
Fining upwards sandstone. Trough cross to planner laminated.
Silty shale. Wavy planer to ripple laminated with occassional carbonaceous debris.
Fining upward sandstone, rooted at top of bed. Abundant bioturbation with Macaronichnus segregatus in bottom 1.2 meters of bed.
Trough cross and planer laminated medium to upper fine grained sand interbeds.
Swaley to hummocky cross laminated to scrambled coarsening upwards very fine sandstone.

# Appendix 2: SHOREFACE GROSS SAND MAP

The following appendix contains a map of the gross sand and conglomerate isopach for the Notikewin R1 and R2 within the study area. It was constructed using 360 well logs compared with the 51 cores logged as part of this thesis


T68
T67
T66
T65
R13
R12
R11
R10
R9
R8
R7
LEGEND:
contour intervals
in meters
10-11
12-13
14-15
16-17
18-19
20-21
22-23
24-25
26-27
28-29
30-31
32-33
34-35
36+
km
0
5
10
15